Ultrasonics 71 (2016) 127–133

Contents lists available at ScienceDirect

Ultrasonics

journal homepage: www.elsevier.com/locate/ultras

Evaluation of healthy muscle tissue by strain and shear wave elastography – Dependency on depth and ROI position in relation to underlying bone

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ARTICLE INFO

Article history:
Received 16 October 2015
Received in revised form 3 April 2016
Accepted 10 June 2016
Available online 11 June 2016

Keywords:
Ultrasound
Elastography
Musculoskeletal
Strain
Shear-wave

ABSTRACT

Purpose: The aim of this study was to evaluate the influence of depth and underlying bone on strain ratios and shear wave speeds for three different muscles in healthy volunteers. For strain ratios the influence from different reference region-of-interest positions was also evaluated.
Material and methods: Ten healthy volunteers (five males and five females) had their biceps brachii, gastrocnemius, and quadriceps muscle examined with strain- and shear wave elastography at three different depths and in regions located above bone and beside bone. Strain ratios were averaged from cine-loops of 10 s length, and shear wave speeds were measured 10 times at each target point. The distance from the skin surface to the centre of each region-of-interest was measured. Measurements were evaluated with descriptive statistics and linear regression.
Results: Linear regression showed a significant influence on strain ratio measurements from the reference region-of-interest position, i.e. being above the same structures as the target region-of-interest or not (means: 1.65 and 0.78; ($P < 0.001$)). For shear wave speeds, there was a significant influence from depth and location above or beside bone ($P = 0.011$ and $P = 0.031$).
Conclusion: Strain ratio values depend significantly on reference and target region-of-interest being above the same tissue, for instance bone. Strain ratios were not influenced by depth in this study. Shear wave speeds decreased with increasing scanning depth and if there was bone below the region-of-interest.

1. Introduction

Elastography is a rapidly evolving ultrasound (US) technique. Commercially, three main techniques are available: transient elastography, strain elastography, and shear wave elastography [1]. In transient elastography mechanical stress is applied by a piston, which compresses the skin with a known frequency and the speed of shear waves perpendicular to the direction of tissue compression is measured. The square of shear wave speed is proportional to tissue stiffness. A B-mode image is not commercially available for this method, which has mainly been evaluated for hepatic fibrosis [2]. In strain elastography (SE) mechanical stress is applied manually by compressing the skin with the transducer. The tissue strain is measured relative to the surrounding tissue and translated into a colour-coded map, which is shown as an overlay on the B-mode image. The method is qualitative, but a semi-quantitative measurement, a strain ratio (SR), may be applied. To calculate an SR a region of interest (ROI) is placed in the area of interest, for instance in a tumour, and a reference ROI is placed in neighbouring healthy tissue. The SR is calculated as the average strain in the reference ROI divided by the average strain in the tumour ROI. A value above 1 indicates that the tumour is harder than the reference, if the stress in the ROI and reference can be considered equal. SE has been evaluated in phantoms, in lymph nodes, breast tumours, pancreatic- and thyroid lesions [3–7]. Shear wave speed elastography (SWSE) is the only commercially available quantitative method where a B-mode image is available. Speeds of shear waves, which appear perpendicular to an acoustic ultrasound pulse emitted by the transducer are measured and reported by the system.

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http://dx.doi.org/10.1016/j.ultras.2016.06.007
0041-624X/

The method is well evaluated in liver fibrosis, and in breast and thyroid nodules [1,8–12].

Few studies have been published on elastography for musculoskeletal applications and most of these studies are on tendons, which consist of more homogeneous fibres than muscles [13,14], where the insonation angle of the fibres may be more diverse [15,16]. In musculoskeletal ultrasound one of the pitfalls is anisotropy, where the ultrasound beam may be reflected in a different direction than the ultrasound transducer, especially if the insonation angle is 90°. Due to the different pennation of the muscle fibres some elastography signal may be lost [17,18].

Our hypotheses were that SRs and SWSEs are dependent on depth, and that the relation of target and reference ROI to underlying bone would influence the SR value.

The aim of this study was to evaluate the influence of depth and underlying bone on SR values and SWSE measurements for three different muscles in healthy volunteers, and for SR also to evaluate the influence from different reference ROI placing.

2. Material and methods

2.1. Test persons

Ten healthy volunteers (5 males and 5 females) with a median age of 32.5 years (range: 26–55 years) gave oral informed consent to participate in the study. The Regional Ethical Committee on Medical Research approved this study (H-2-2014-FSP72). None of the volunteers were athletes, but all were in a good physical shape (exercise: 1–7 h a week) and had BMI < 30. All volunteers had three different muscles examined in the resting position: the biceps brachii, the gastrocnemius, and the quadriceps. These were measured perpendicular to the fibre direction at different depths. All muscles were examined in a relaxed state. When examining the biceps, the volunteers were sitting on a chair with the forearm resting and the antebrachial extensors facing upwards. For the gastrocnemius the volunteers were lying on the examination bed in the prone position with the feet relaxed, hanging from the bed. For the quadriceps the vastus medialis was examined with the volunteer lying supine, with the legs rotated slightly outwards.

2.2. Ultrasound

All volunteers were examined with two different US systems. One system, a GE Logiq E9 (GE Healthcare, Chalfont St. Giles, UK), was used for SE, another, an Acuson S3000 Helx (Siemens Mountain View, CA, USA), was used for SWSE. For SE either a high frequency, linear array probe (9L) or a low frequency, curved array probe (C1-5) was used depending on scanning depth. For SWSE a high frequency, linear array probe (9L4) or a low frequency, curved array probe (4C1) was used. SWSE measurements were reported in m/s. The distance from nearby joints (elbows and knees) was measured and recorded to obtain equal measuring points between the two scanning sessions.

2.3. Elastography

For SE an image in the axial plane, including bone in the lower part of one half of the image was obtained (Fig. 1). The elastography box was set to cover the entire image. Soft repetitive compressions of the skin with a frequency of 80–100 per minute were applied. Cine loops of 10 s were recorded. ROIs were placed after all recordings had been performed: 6 small ellipsoid ROIs in three different depths (target ROIs), avoiding the 0.2 cm closest to the skin surface, as the signal is only recorded > 1.2 mm from the transducer [14] and also avoiding inclusion of bone. Three target ROIs were placed above the bone and three were placed beside the area with bone. Reference ROIs were two large ellipsoids that covered the three small ROIs, one above the bone and one beside the area with bone (Fig. 2). In each of the three muscles 12 SR's were calculated: 3 target ROIs above bone with the reference ROI not above bone (Fig. 2A), 3 target ROIs not above bone with the reference ROI above bone (Fig. 2B), 3 target ROIs above bone with the reference ROI encompassing them (Fig. 2C), 3 target ROIs not above bone with the reference ROI encompassing them (Fig. 2D). This added up to 36 SRs for each volunteer giving a total of 360 SR values.

Calculations were averaged based on values from the entire 10 s cine loop and performed by the US system. The distance from the skin surface to the centre of each target ROI was also recorded.

For SWSE the same target ROIs in three depths, beside and above bone, were examined with the transducer perpendicular to

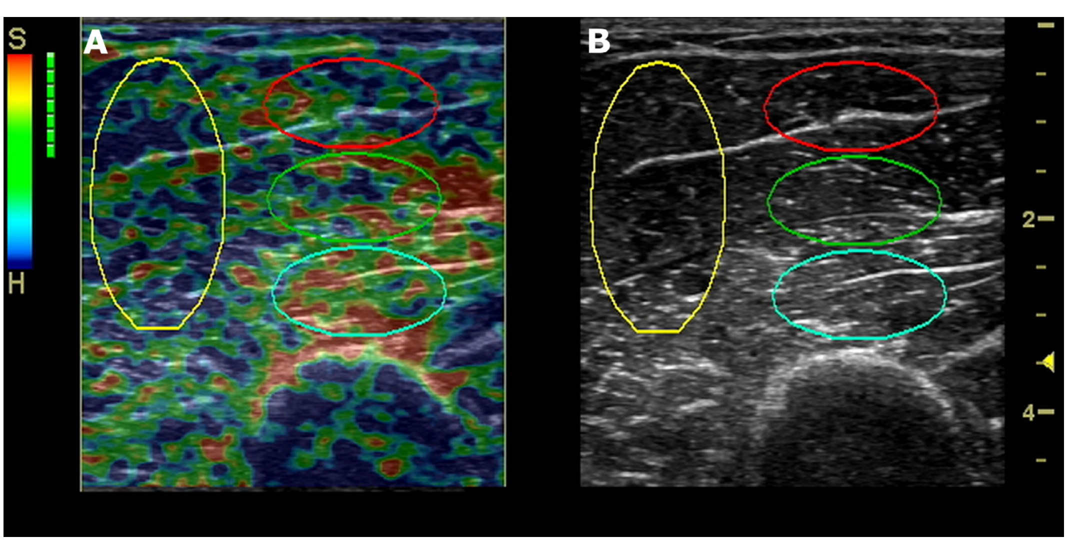

Fig. 1. Strain elastography (SE). A. A strain colour map is overlaid on the B-mode image of the quadriceps muscle. B. Corresponding B-mode image. ROIs in three depths above bone and the reference ROI beside them. The green vertical bar is the quality indicator. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)