Introduction

Magnetic Resonance Elastography (MRE) is a relatively new, non-invasive diagnostic method with great potential, enabling the assessment of biomechanical properties of soft tissues in the human body. By measuring biophysical parameters such as tissue stiffness, MRE allows the evaluation of the risk and severity of various pathological processes, including fibrosis, inflammation, or cancer. MRE combines elements of physics, mechanics, computer science, and medicine, making it an interdisciplinary technique that is also complex and time-consuming to interpret. Despite the dynamic development of this technology, the influence of many factors—including physiological ones—on the biomechanical parameters obtained via MRE has not yet been fully understood. Moreover, the feasibility of the examination largely depends on patient cooperation and the equipment used. MRE is typically performed during breath-hold, which is not always possible, especially in patients with respiratory difficulties. Additionally, the commercially available passive driver is mainly designed for imaging large organs such as the liver or spleen, limiting the application of MRE in other anatomical regions.

Aim of the study

The aim of this study was to contribute to the development of MRE by: a) assessing the influence of meal intake and liver iron content on liver stiffness in healthy volunteers, b) developing an algorithm enabling free breathing liver MRE by reducing motion artifacts, c) developing an algorithm for automatic segmentation of the myocardial muscle in cardiac MRE, and d) designing a dedicated passive driver to enable MRE of the parotid glands.

Materials and Methods

The impact of food intake and liver iron content on liver stiffness was assessed in a group of 100 healthy volunteers. All participants underwent blood laboratory tests and liver stiffness measurements using MRE in a fasting state and at one or several time intervals after meal consumption. Additionally, the R2* parameter, which correlates with liver iron content, was determined. Statistical analysis was performed to assess correlations between the measured parameters.

To develop an algorithm for motion artifact reduction during breathing, a group of 41 volunteers was examined twice—once during breath-hold and once during free breathing. A neural network based on the SegNet architecture was trained to generate reference-like images (from breath-hold scans) based on raw MRE images acquired during free breathing. These images were then inverted to generate stiffness maps, which were compared to reference maps.

The algorithm for automatic myocardial segmentation in cardiac MRE was developed using data from 16 healthy volunteers. Three deep learning approaches, four input data combinations, and seven neural network architectures were tested. The models were trained to generate myocardial masks corresponding to manually drawn reference masks.

The dedicated passive driver was designed to deliver vibrations as close as possible to the examined region. The new driver was made from flexible materials and could be mounted directly on the subject's face using a Velcro strap. It was tested on a group of three healthy volunteers using both 2D and 3D MRE.

Results

No correlation was found between liver stiffness values measured in the fasting state and the R2* parameter in the studied group of healthy volunteers ($r = -0.04$, $p = 0.68$). However, a statistically significant ($p < 0.01$) postprandial increase in liver stiffness was observed, lasting up to 2 hours and 30 minutes after meal intake.

The AI-based algorithm for motion artifact reduction significantly improved the quality of stiffness maps obtained during free breathing. The resulting liver stiffness values (5.67 ± 1.58 kPa, range 4.45–9.34 kPa) were closer to the reference values (4.90 ± 1.41 kPa, range 3.41–7.84 kPa) than those obtained without correction (7.59 ± 1.11 kPa, range 6.58–10.09 kPa).

The developed algorithm for automatic myocardial segmentation demonstrated high segmentation accuracy (Dice coefficient = 0.77 ± 0.07, intersection over union = 0.63 ± 0.09, precision = 0.68 ± 0.08, sensitivity = 0.90 ± 0.07, specificity = 0.99 ± 0.01, AUROC = 0.95 ± 0.03, Hausdorff distance = 2.67 ± 0.19), significantly accelerating the interpretation of cardiac MRE studies.

The designed passive driver enabled MRE of the parotid glands in both 2D and 3D MRE, demonstrating the feasibility of such examination. Using 3D MRE, it was possible to perform measurements at a vibration frequency of 120 Hz, which significantly enhances the reliability of stiffness, viscosity, and other biophysical parameter assessments of the parotid glands.

Conclusions

Main conclusion:

The developed solutions address significant limitations of magnetic resonance elastography and represent a major step toward the further advancement of this technique.

Conclusions from the implementation of specific objectives:

1. The influence of meal intake and liver iron content on liver stiffness measured by MRE was determined.
2. An algorithm based on the SegNet architecture was developed to reduce respiratory motion artifacts in liver MRE.
3. A deep learning-based model was created for automatic myocardial segmentation in cardiac MRE.
4. A new dedicated passive driver was designed, enabling MRE and reliable assessment of stiffness, viscosity, and other biophysical parameters of the parotid glands.