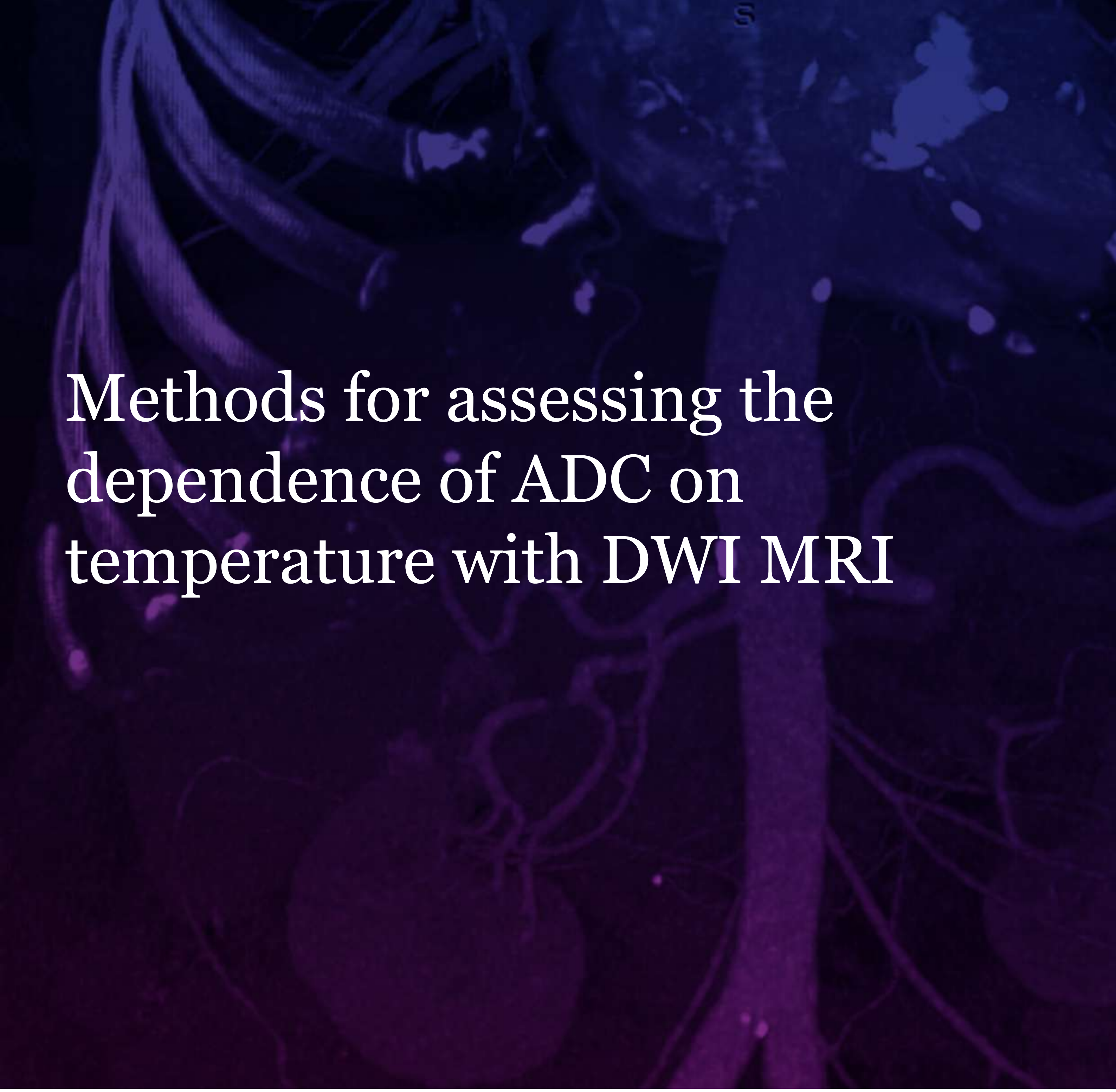

Methods for assessing the dependence of ADC on temperature with DWI MRI

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Purpose of the study

The purpose of this study is to develop a methodology for assessing the temperature dependence of the measured diffusion coefficient (ICD), calculated when performing diffusion-weighted magnetic resonance imaging (MRI).

Materials and methods

To create different ICDs, physical models of obstructed diffusion were used, which are aqueous solutions of the polymer (polyvinylpyrrolidone) with different concentrations. The temperature of the solutions was measured using a fiber optic temperature measurement system with sensors fixed inside the tubes. The dependence of the change in ICD on temperature was recorded when the EPI sequence was periodically started while the phantom was cooling from 38 °C to 22 °C.

Results

As a result of an experimental study, ICD temperature dependences were obtained for each model of diffusion obstructed. Approbation of the technique showed that in the temperature range allowed in the MRI room by the current regulatory documentation (20-23 °C), the values of ICDs can differ by up to 25 %. Calculated approximating coefficients of the dependence of ICD on temperature for the used PVP solutions.

Conclusion

The presented experimental technique allows to increase the efficiency of the procedure of periodic quality control using a phantom for diffusion-weighted magnetic resonance imaging by introducing a correction factor.

Keywords:

diffusion-weighted magnetic resonance imaging, apparent diffusion coefficient, quality control

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Introduction

Diffusion-weighted magnetic resonance imaging (DWI MRI) is one of the methods of medical visualization applied for detection and assessment of neoplasms. Apparent diffusion coefficient (ADC), a quantitative parameter which reflects the movement of water molecules within tissue, is a specific feature of this mode. The use of ADC values in order to form the conclusion about the probable malignancy of the tumor [1, 2] necessitates controlling of the accuracy and repeatability of this indicator measurement [3].

Traditionally, image quality control in radiology involves the use of phantoms – special test objects with known properties. Obtained phantom images allow to judge about the correct operation of the equipment and to decide whether this equipment should be further used and if there is a need for correction factor.

The accuracy of ADC measurement depends on such factors as the gradient calibration accuracy and gradient amplitude. The direct control of these two parameters is difficult so a phantom was developed [4]. The phantom allows to simulate the entire range of self-diffusion coefficients recorded in organ tissue including different types of diffusion (limited, difficult, and unlimited) [5] and as a result to improve the accuracy of ADC measurement with correction factor. Comparison of different devices confirms the difference in ADC values determined not only on the equipment of different manufacturers, but also on tomographs of the same model located in different medical institutions [6], and therefore confirms the need of introducing control methods and equipment cross-calibration in practice.

The next step is to investigate the influence of sample temperature on the recorded ADC values in addition to the above mentioned factors contributing to ADC measurement. Temperature fluctuation are generally explained by the variable air temperature in the MRI treatment room (20–23 °C according to SanRaN 2.1.3.2630-10 [7]), tomograph and climate control unit hearth heat.

Thus, the main purpose of the study is to develop method of assessing the dependence of ADC samples on temperature.

Materials and methods

The Einstein-Smoluchowski equation is the most famous equation to represent the dependence of self-diffusion coefficient on temperature:

$$D = \frac{kT}{3\pi\eta d}, \quad (1)$$

where η – viscosity, d – particle size, k – Boltzmann's constant, T – absolute temperature.

However, only estimated values can be obtained when applying the equation for this problem due to macroscopic approximations used for this equation (1) limit its application. Therefore, the Einstein-Smoluchowski equation was used only for evaluative calculations while selecting materials for the phantom. This work offers a method of experimental determination of the dependence of ADC on temperature.

Aqueous solutions of the polyvinylpyrrolidone (PVP) with different concentrations (0 (water), 10, 30, 50, 70 %) were used for modeling obstructed diffusion resulting from the collisions between water molecules and macromolecules, cell organelles, and compartments. Tubes with this solutions were placed on a special frame in nonmagnetic plastic container filled with water.

According to IEC 60601-2-33:2010 [8] it is prohibited to conduct MRI if the local body temperature exceeds 39 °C. A preheat of the phantom and conducting MRI in (DW) MRI mode while the phantom cools down appeared to be the rational decision.

Accurate measurement of solutions temperature in the phantom is also challenging. The following methods are traditionally used for this purpose: MR-termometry, non-contact measurements (e.g. thermography), measurements with contact sensors. The experience in this kind of studies showed that it is preferable to use fiber-optic temperature sensors that are resistant to magnetic fields and have high accuracy (up to 0.01 °C) [9]. In addition, the response time of the sensors is negligibly short compared to the scanning time, which makes is possible to assess the correctness of the data used.

The control unit of multichannel fiber-optic system of deformation and temperature measurement "ASID-12" manufactured by Optiz-Monitoring Ltd. (figure 1) was located in the MRI technical room. The sensors were led through a technological hole in the Faraday cage and fixed in the test tunes centers. An alcohol thermometer was used to monitor fiber-optic system measurements.

Picture 1. *The control unit of fiber-optic system for temperature measurement*

In order to ensure a gradual temperature change before the study the phantom was thermostatted by placing it into flowing water with temperature of 38.0 °C. Air temperature in the MRI treatment room was – 23,0 °C.

Scanning was performed on Toshiba Excelart Vantage 1,5 T using DWI_EPI pulse sequence with the following parameters: TR 5300 ms, TE 100 ms, FOV 26 x 26 sm, matrix 128 x 128, slice number 15, b-value = 600, 800 s/mm2, scanning time 32 s. The scanning was started with the following frequency: 38 – 34 °C – every minute, 34 – 30 °C – every 2 minutes, 30 – 28 °C – start every 5 minutes.

The statistical analysis of the received ADC maps data was carried out as follows:

- with the help of developed software the regions of interest covering about 80 % of sample cross-section area for each tube (ROIj) were identified in the MR-images;

- the calculation of the average value of ADC Dj and the standard deviation σj was performed in the automatic mode on the sample Di,j, i = 1, 2 … Nj, where Nj is the number of pixels within the ROIj;

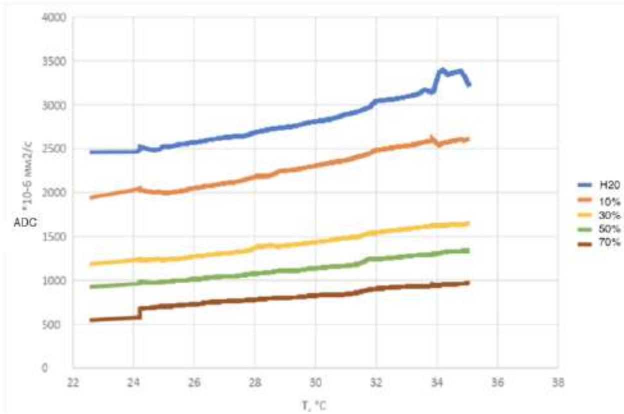
- pixels selected erroneously and corresponding to the condition (2) were excluded from the obtained sample.

$$D_{ij} \notin \left(D_j - 3\sigma_j, D_j - 3\sigma_j\right); \quad (2)$$

At the same time, the average temperature value, obtained from the sensors during the study, was taken as true temperature value.

Results

Picture 2 shows the dependence of ADC solutions of the phantom on temperature obtained as a result of the proposed method.



Picture 2. *The temperature dependency graph fo ADC for different PVP concentrations*

Testing of the technique showed that within the temperature range allowed by the current regulatory documentation, registered ADC values may vary up to 25 %. The study of the dependence of ADC on temperature allowed to conduct approximation curves and calculate their coefficients.The closest linear function for the PVP solutions with concentrations of 50 % and 70 % was y = a*x + b. Coefficients a and b are determined using the least squares method. Table 1 shows the calculated coefficients.

The dependence of ADC on temperature has a quadratic function y = c*x2 + a*x + b for aqueous PVP solutions with concentrations of 0, 10, and 30 %.

Table 1. *Approximating coefficients for the dependence of ADC on temperature for specified water PVP solutions*

	PVP 50 %	PVP 70 %	PVP 0 %	PVP 10 %	PVP 30 %
c	0	0	4.73	1.49	0.71
a	35.55	89.90	-199.49	-26.96	-0.73
b	29.63	-59.68	4550.10	1776.50	816.25

The use of calculated approximating coefficients allows to correct ADC measurements performed under different temperature conditions and to conduct comparative tests to compare the results obtained from different tomographs.

A peak of water diffusion coefficient values at 34

– 35 °C may be due to the fluid movements inside the phantom caused by its movements with the patient table during initial positioning.

High accuracy and repeatability of ADC measurement at (DW) MRI is the result of this method.

Conclusion

This work has shown the possibility and timeliness of assessing the dependence of ADC on temperature using (DW) MRI to ensure the quality of performed MR-studies. The presented experimental method allows to increase the efficacy of periodic quality control procedure with the use fo phantom for diffusion-weighted magnetic resonance imaging by introducing a correction factor.

The results of this work can also be used while developing recommendations for ADC measurement for diagnostic purposes.

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