ORIGINAL RESEARCH ARTICLE

NATIONAL JOURNAL NJMR MEDICAL RESEARCH

Role of TR (Repetition Time) and TE (ECHO Time) in Optimization of Magnetic Resonance Spectroscopy in the Brain Protocol

Sumit Tyagi[1*], Ashok Sharma[2], Subhash Chand Sylonia[3], Lalit Gupta[4]

[1]Radiology and imaging technology, Santosh deemed to be University, Gaziabad, India
[2]Radio diagnosis, Santosh deemed to be University, Gaziabad, India
[3]Radio diagnosis, Saraswati Institute of Medical Sciences Anwarpur Hapur, Hapur, India
[4]Radiology and imaging technology, Santosh deemed to be University, Gaziabad, India

DOI:
10.55489/njmr.150220251050

***Corresponding author**:
Dr. Sumit Tyagi
(Email: Sumittyagi50@gmail.com)

Date of Submission: 19/12/2024
Date of Acceptance: 18/02/2025
Date of Publication: 01/04/2025

Funding Support:
None Declare

Conflict of Interest:
The authors have declared that no conflicts of interest exist.

How to cite this article:
Tyagi S, Sharma A, Sylonia SC, Gupta L. Role of TR (Repetition Time) and TE (ECHO Time) in Optimization of Magnetic Resonance Spectroscopy in the Brain Protocol. Natl J Med Res 2025;15(02):77-81. DOI: 10.55489/njmr.150220251050

ABSTRACT

Introduction: Magnetic Resonance Spectroscopy (MRS) is a non-invasive imaging modality used to quantify brain metabolites, aiding in the diagnosis of neurological disorders. Optimization of acquisition parameters, especially Repetition Time (TR) and Echo Time (TE), is critical for enhancing signal-to-noise ratio (SNR) and metabolite detection.

Method: This six-month study involved 100 participants undergoing brain MRS at two tertiary care centers. MRS examinations were performed using a 1.5 Tesla scanner with single-voxel PRESS sequences. TR values (1500–2000 ms) and TE values (30 ms, 144 ms) were varied systematically to assess their impact on SNR, spectral resolution (FWHM), and metabolite detection. Statistical analysis included ANOVA and correlation studies.

Results: Longer TR values significantly improved SNR (12.3 ± 1.8 at TR = 1500 ms vs. 14.7 ± 2.1 at TR = 2000 ms; $p < 0.001$). Higher TE values enhanced spectral resolution (FWHM: 0.050 ± 0.005 ppm at TE = 30 ms vs. 0.045 ± 0.004 ppm at TE = 144 ms; $p < 0.01$). Diagnostic accuracy was highest for brain tumors (90%). TR and SNR showed a strong positive correlation ($r = 0.851$; $p < 0.001$).

Conclusion: Optimized TR and TE values significantly enhance metabolite quantification and diagnostic accuracy in MRS, particularly for brain tumors and neurodegenerative diseases.

Keywords: Magnetic Resonance Spectroscopy, Repetition Time, Echo Time, Metabolite Detection, Neurological Disorders, Signal-to-Noise Ratio

INTRODUCTION

Magnetic Resonance Spectroscopy (MRS) has emerged as a vital non-invasive imaging modality for the biochemical assessment of brain tissue. Unlike conventional MRI, which provides anatomical details, MRS enables the quantification of metabolites such as N-acetylaspartate (NAA), choline, creatine, lactate, and myo-inositol, offering unique insights into brain physiology and pathology. This makes MRS particularly valuable in the diagnosis and monitoring of neurological disorders, including brain tumors, neurodegenerative diseases, and metabolic disorders.[1]

Publisher: Medsci Publications [www.medscipublications.com] ISSN: 2249 4995 Official website: www.njmr.in

The accuracy and reliability of MRS heavily depend on the optimization of its acquisition parameters, among which Repetition Time (TR) and Echo Time (TE) play a critical role. TR, the time between successive pulse sequences, and TE, the interval between the application of the excitation pulse and signal acquisition, significantly influence the quality, signal-to-noise ratio (SNR), and metabolic information captured during MRS. Selecting appropriate TR and TE values is crucial for enhancing the detection of specific metabolites and minimizing overlapping signals or noise.[2]

The brain presents unique challenges for MRS optimization due to the complex biochemical environment and the need for high spectral resolution. While long TR and short TE are generally preferred for maximizing SNR and metabolite detection, the optimal settings vary depending on the target metabolites, clinical application, and scanner specifications. Despite advancements in MRS technology, the lack of standardized protocols often leads to inconsistent results, underscoring the need for detailed investigations into parameter optimization.[3]

This study aims to evaluate the role of TR and TE in optimizing brain MRS protocols. By systematically analyzing the impact of these parameters on spectral quality and metabolite quantification, this research seeks to provide evidence-based recommendations for improving the diagnostic utility of MRS in clinical and research settings. This optimization not only enhances the accuracy of brain metabolite assessment but also broadens the clinical applications of MRS, paving the way for its integration into routine neuroimaging protocols.

MATERIALS AND METHODS

This study was conducted over a period of 6months, involving 100 participants undergoing brain Magnetic Resonance Spectroscopy (MRS) for various clinical indications. The study was carried out at two tertiary healthcare centers: Santosh Hospital, Ghaziabad, and Saraswati Institute of Medical Sciences, Anwarpur, Hapur. Ethical clearance was obtained from the institutional ethics committees of both centers, and written informed consent was secured from all participants.

Participants included in the study were patients suspected of having neurological disorders such as brain tumors, neurodegenerative conditions, metabolic abnormalities, or other brain pathologies requiring MRS evaluation. The inclusion criteria encompassed individuals aged 18–75 years, with no contraindications to MRI (e.g., metallic implants or claustrophobia). Patients with significant motion artifacts or incomplete MRS data were excluded from the analysis.

All MRS examinations were performed using a 1.5 Tesla MRI scanner with a standard single-voxel PRESS (Point Resolved Spectroscopy) sequence. Repetition Time (TR) and Echo Time (TE) were systematically varied to optimize metabolite detection. The TR values ranged from 1500 ms to 2000 ms, while TE values were tested at 30 ms and 144ms to assess their impact on signal-to-noise ratio (SNR) and spectral resolution. Metabolites of interest, including N-acetylaspartate (NAA), choline, creatine, lactate, and myo-inositol, were quantified, and their visibility and spectral quality were analyzed under different TR and TE settings.

Data were collected in a standardized manner, and spectral quality was evaluated by assessing the full width at half maximum (FWHM) and SNR. Comparative analysis was performed to determine the optimal TR and TE values for enhanced detection of key brain metabolites. Statistical analysis included descriptive statistics for baseline characteristics and paired t-tests or ANOVA to compare spectral quality across different parameter settings, with a p-value <0.05 considered statistically significant. This study approved by the ethical committee of Santosh Deemed to be University, Ghaziabad, NCR Delhi. (Letter No. SU/R/2024/1548[17] Dated 07-06-2024.)

This study aimed to identify the most effective TR and TE combinations for optimizing brain MRS protocols, thereby improving its diagnostic utility in clinical practice. The findings are expected to contribute to the standardization of MRS protocols, ensuring consistent and accurate metabolite detection in neurological conditions.

RESULTS

The demographic and clinical characteristics of the study population are summarized in Table 1. The mean age of the participants was 44.8 ± 13.2 years. Regarding gender distribution, 57% of the participants were male, and 43% were female. The primary indications for MRS included brain tumors (57%), neurodegenerative diseases (29%), metabolic disorders (19%), and other conditions (8%). These data provide a comprehensive overview of the study population's demographic and clinical profiles.

Table 1: Demographic and Clinical Characteristics of the Study Population

Variable	Cases
Age (years) (Mean ± SD)	44.8 ± 13.2
Gender	
Male	57
Female	43
Indications for MRS	
Brain Tumour	57
Neurodegenerative Disease	29
Metabolic Disorder	19
Other	8

Table 2: Spectral Quality (SNR) Across Different TR Values

TR (ms)	Mean SNR ± SD	p-value
1500	12.3 ± 1.8	<0.001
2000	14.7 ± 2.1	

The analysis of spectral quality, measured in terms of signal-to-noise ratio (SNR), revealed a significant improvement with increasing Repetition Time (TR).

Table 3: Spectral Resolution (FWHM) Across Different TE Values

TE (ms)	Mean FWHM (ppm) ± SD	p-value
30	0.050 ± 0.005	<0.01
144	0.045 ± 0.004	

Table 4: Detection Rate of Metabolites Under Different TR and TE Combinations

Metabolite	TR 1500 ms	TR 2000 ms	TE\ 30 ms	TE 144ms
NAA	87%	96%	91%	98%
Choline	73%	86%	79%	91%
Creatine	71%	82%	84%	89%
Lactate	54%	62%	64%	74%

Table 5: Comparison of Diagnostic Accuracy for Neurological Conditions Based on Optimized TR and TE

Condition	Sensitivity	Specificity	Accuracy
Brain Tumors	92%	87%	90%
Neurodegenerative Diseases	89%	86%	87%
Metabolic Disorders	83%	81%	82%

Table 6: Statistical Correlation Between Parameter Settings and Metabolite Detection

Parameter	Correlation Coefficient (r)	p-value
TR and SNR	0.851	<0.001
TE and FWHM	-0.789	<0.001

At a TR of 1500 ms, the mean SNR was 12.3 ± 1.8, which progressively increased to 14.7 ± 2.1 at 2000 ms, the differences in SNR across the TR values were statistically significant ($p < 0.001$, ANOVA). This trend indicates that longer TR values result in enhanced SNR, likely due to improved relaxation time for tissue signal recovery.

The spectral resolution, assessed by the Full Width at Half Maximum (FWHM) in parts per million (ppm), improved significantly with increasing Echo Time (TE). At a TE of 30 ms, the mean FWHM was 0.050 ± 0.005 ppm, which decreased to 0.045 ± 0.004 ppm at 144 ms. The observed differences in FWHM across these TE values were statistically significant ($p < 0.01$).

The detection rates of various metabolites under different TR and TE combinations are detailed in Table 4. For NAA, the detection rate improved from 87% at TR 1500 ms to 96% at TR 2000 ms and increased further from 91% at TE 30 ms to 98% at TE 144 ms. Similarly, Choline detection showed a marked improvement from 73% at TR 1500 ms to 86% at TR 2000 ms and from 79% at TE 30 ms to 91% at TE 144 ms. For Creatine, the rates increased from 71% at TR 1500 ms to 82% at TR 2000 ms and from 84% at TE 30 ms to 89% at TE 144 ms. Lastly, Lactate detection was the lowest among all metabolites but still demonstrated an improvement from 54% at TR 1500 ms to 62% at TR 2000 ms and from 64% at TE 30 ms to 74% at TE 144 ms.

These results indicate that optimizing both TR and TE significantly enhances metabolite detectability, particularly for NAA and choline. A TR of 2000ms and a TE of 144ms provide the most favourable conditions for accurate and reliable metabolite detection in brain MRS.

Table 5 shows the diagnostic accuracy for various neurological conditions based on optimized TR and TE parameters. For brain tumors, the sensitivity was 92%, the specificity was 87%, and the overall accuracy reached 90%. Neurodegenerative diseases demonstrated slightly lower values, with a sensitivity of 89%, specificity of 86%, and an accuracy of 87%. Metabolic disorders showed the lowest diagnostic performance among the three categories, with sensitivity, specificity, and accuracy recorded at 83%, 81%, and 82%, respectively. These findings highlight the effectiveness of optimized TR and TE in achieving high diagnostic precision across different neurological conditions.

Table 6 shows the statistical correlation between parameter settings and metabolite detection. A strong positive correlation was observed between TR and SNR, with a correlation coefficient (r) of 0.851 and a highly significant p-value of <0.001. Conversely, a strong negative correlation was found between TE and FWHM, with $r = -0.789$ and a similarly significant p-value of <0.001. Additionally, a moderate positive correlation was noted between TR and metabolite detection, with $r = 0.653$ and a p-value of <0.01. These results underscore the significant impact of parameter optimization on metabolite detection accuracy.

DISCUSSION

Our study demonstrated that increasing the Repetition Time (TR) significantly enhances the spectral quality, as indicated by the signal-to-noise ratio (SNR). Comparing our findings with previous studies, Kellman et al. (2003)[4] noted that longer TR values could compensate for SNR loss in parallel imaging techniques, emphasizing the positive impact of TR on SNR.

Ebel and Maudsley (2003)[5] discussed improved spectral quality in problematic brain regions using a modified acquisition strategy but reported an SNR reduction by a factor of 1.4–1.6 due to matrix size adjustments. Despite this reduction, their results highlighted the importance of balancing acquisition parameters for optimal spectral outcomes. Our findings reinforce the need for parameter optimization, showing that increasing TR within the specified range enhances spectral quality without compromising SNR.

Jahanian et al. (2019) [6] compared functional connectivity using short TR (350 ms) and standard TR (2000 ms) in rs-fMRI. While their study focused on functional imaging rather than spectroscopy, they reported improved signal-noise separation with longer TR, consistent with our findings on SNR improvements.

Our study showed a significant improvement in spectral

resolution (FWHM in ppm) with increasing Echo Time (TE). While there is limited direct evidence in the literature comparing FWHM across TE values in brain spectroscopy, some studies show the importance of spectral resolution in various contexts. Serdyuchenko et al. (2014)[7] investigated ozone absorption cross-sections with spectral resolutions ranging between 0.02–0.24 nm (FWHM), emphasizing the importance of high spectral resolution for accurate measurements. Similarly, Xu et al. (2021)[8] achieved a high spectral resolution with an FWHM of 0.1 Å in an EUV spectrometer, highlighting advancements in resolution across different modalities.

In imaging modalities like ultrasound, Jing and Lindsey (2020)[9] reported improvements in lateral FWHM, demonstrating a decrease of up to 38.24% in simulations, which underscores the critical role of FWHM in enhancing imaging quality. These findings parallel our observations in MRS, where lower FWHM indicates better spectral clarity and resolution.

Our study highlights the crucial role of TR and TE optimization in improving the detection rates of key brain metabolites in MRS. These findings align with previous studies that examined metabolite detectability across varying MRS parameters. Short TE values (30–39 ms) are widely recognized for their ability to reliably detect NAA, Cho, Cr, and myo-inositol (mI), with coefficients of variation for absolute metabolite concentrations ranging from 3.3–4.0% in vitro and 3.8–6.4% in vivo (Schirmer & Auer, 2000)[10] . Similarly, Chiu et al. (2013)[11] and Wiedermann et al. (2001)[12] confirm the utility of short TE in detecting a wide range of metabolites, including lactate, under certain pathological conditions.

Longer TE values (136–144 ms) are preferable for identifying metabolites like lactate, which becomes more prominent under these conditions (Duijn et al., 1992[13]; Sutton et al., 1992).[14] However, detection of mI may be reduced at longer TE values (Alkan et al., 2004;[15] Harris et al., 2007)[16]. TR values of 1500–2000 ms, commonly used in MRS studies, provide reliable quantification of major metabolites (Schirmer & Auer, 2000;[10] Schott et al., 2010)[17].

While most studies focus on general trends, our results demonstrate that longer TR (2000 ms) and intermediate to long TE values (144–288 ms) are particularly effective for maximizing the detection rates of metabolites like NAA and Cho, which are crucial markers of neuronal integrity and membrane turnover, respectively.

Our study shows that optimizing TR and TE values in MRS protocols significantly improves diagnostic accuracy for neurological conditions. In comparison, other imaging modalities have shown variability in diagnostic accuracy for similar conditions. Conventional MRI provides high specificity (85.2–100%) for brain tumors but variable sensitivity depending on tumor type and grade (Julià-Sapé et al., 2006).[18] Integration with diffusion-weighted imaging has been shown to improve tumor grading accuracy (Guzmán-De-Villoria et al., 2014)[19]. Transcranial ultrasonography, while effective for detecting intracranial masses (sensitivity 97%, specificity 99%), demonstrates limited utility for neurodegenerative diseases, with sensitivity and specificity dropping to 80% and 71%, respectively (Allen et al., 2023).[20]

FDG-PET, particularly with optimized statistical parametric mapping, has shown superior accuracy for neurodegenerative diseases, achieving a sensitivity of 96% and specificity of 84% (Perani et al., 2014)[21]. This technique excels in the differential diagnosis of conditions like Alzheimer's disease and frontotemporal dementia. High spatiotemporal resolution MRI has also been explored, with gray matter specificity exceeding 96% and sensitivity above 75%, offering a promising approach for functional connectivity studies in neuropsychiatric conditions (Tomasi et al., 2015).[22]

Our study reveals key correlations between parameter settings and metabolite detection in brain MRS. Longer Repetition Times (TR) enhance the Signal-to-Noise Ratio (SNR), improving spectral quality for better metabolite detection. Additionally, a strong negative correlation was found between TE and FWHM, and a moderate positive correlation was observed between TR and metabolite detection.

These findings align with previous research on the impact of MRS parameters on spectral quality and metabolite detection. For instance, studies have demonstrated that longer TR values improve SNR by allowing more complete T1 relaxation, which enhances metabolite signals (Rizzo & Kreis, 2023) [23]. However, excessively long TRs can increase scan times, necessitating a balance between improved detection rates and practical acquisition times.

The inverse relationship between TE and FWHM observed in our study is consistent with findings by Bartha (2007)[24], who reported improved quantification accuracy for metabolites with smaller linewidths (8-14 Hz FWHM) at TE = 46 ms at 4T. While shorter TEs enable the detection of a broader range of metabolites, they can also introduce spectral overlap, complicating signal differentiation.

Advanced techniques further illustrate the interplay between TR, TE, and metabolite detection. For example, Nassirpour et al. (2016) [25] demonstrated the use of ultra-short TR sequences at 9.4T to reliably map multiple metabolites within clinically feasible timeframes. Similarly, Tsai et al. (2007)[26] employed Proton-Echo-Planar-Spectroscopic-Imaging (PEPSI) to efficiently map metabolite T2 values using short TRs and multiple TEs.

CONCLUSION

The study underscores the critical role of parameter optimization in Magnetic Resonance Spectroscopy (MRS) for enhancing diagnostic accuracy and metabolite detection. Longer TR values significantly improve SNR and metabolite visibility, while longer TE values enhance spectral resolution by reducing FWHM. Optimized TR and TE settings demonstrated robust diagnostic perfor-

mance, particularly for brain tumors and neurodegenerative diseases, achieving high sensitivity, specificity, and accuracy. The findings highlight the importance of tailoring MRS protocols to balance spectral quality, detection efficiency, and scan time, paving the way for more reliable clinical applications in diverse neurological conditions.

Author Contribution: The study was conceived and designed by **ST**, who also contributed to data collection, analysis, interpretation, and manuscript preparation. **AS** was involved in the study design and manuscript preparation. **SCS** contributed to manuscript preparation. **LG** participated in data collection, analysis, interpretation, and manuscript preparation.

REFERENCES

1. Gujar SK, Maheshwari S, Björkman-Burtscher I, Sundgren PC. Magnetic resonance spectroscopy. J Neuroophthalmol 2005; 25: 217-26. DOI: https://doi.org/10.1097/01.wno.0000177307.21081.81 PMid:16148633
2. Lally N, An L, Banerjee D, Niciu MJ, Luckenbaugh DA, Richards EM, et al. Reliability of 7T 1H-MRS measured human prefrontal cortex glutamate, glutamine, and glutathione signals using an adapted echo time optimized PRESS sequence: A between- and within-sessions investigation. Journal of Magnetic Resonance Imaging 2016;43:88-98. DOI: https://doi.org/10.1002/jmri.24970 PMid:26059603 PMCid:PMC4671833
3. Wilson M, Andronesi O, Barker PB, Bartha R, Bizzi A, Bolan PJ, et al. A Methodological Consensus on Clinical Proton MR Spectroscopy of the Brain: Review and Recommendations. MagnReson Med 2019;82:527. DOI: https://doi.org/10.1002/mrm.27742
4. Kellman P, Derbyshire JA, Agyeman KO, McVeigh ER, Arai AE. Extended coverage first-pass perfusion imaging using slice-interleaved TSENSE. MagnReson Med 2004;51:200-4. DOI: https://doi.org/10.1002/mrm.10663 PMid:14705062
5. Ebel A, Maudsley AA. Improved spectral quality for 3D MR spectroscopic imaging using a high spatial resolution acquisition strategy. MagnReson Imaging 2003;21:113-20. DOI: https://doi.org/10.1016/S0730-725X(02)00645-8 PMid:12670597
6. Jahanian H, Holdsworth S, Christen T, Wu H, Zhu K, Kerr AB, et al. Advantages of short repetition time resting-state functional MRI enabled by simultaneous multi-slice imaging. J Neurosci Methods 2019;311:122-32. DOI: https://doi.org/10.1016/j.jneumeth.2018.09.033 PMid:30300699
7. Serdyuchenko A, Gorshelev V, Weber M, Chehade W, Burrows JP. High spectral resolution ozone absorption cross-sections – Part 2: Temperature dependence. Atmos Meas Tech 2014;7:625-36. DOI: https://doi.org/10.5194/amt-7-625-2014
8. Xu Z, Zhang L, Cheng Y, Morita S, Li L, Zhang W, et al. An extreme ultraviolet spectrometer working at 10-130 Å for tungsten spectra observation with high spectral resolution and fast-time response in Experimental Advanced Superconducting Tokamak. NuclInstrum Methods Phys Res A 2021;1010:165545. DOI: https://doi.org/10.1016/j.nima.2021.165545
9. Jing B, Lindsey BD. Phase Modulation Beamforming for Ultrafast Plane-Wave Imaging. IEEE Trans UltrasonFerroelectr Freq Control 2020;67:2003-11. DOI: https://doi.org/10.1109/TUFFC.2020.2993763 PMid:32396082 PMCid:PMC7539262
10. Schirmer T, Auer DP. On the reliability of quantitative clinical magnetic resonance spectroscopy of the human brain. NMR Biomed 2000;13:28-36. DOI: https://doi.org/10.1002/(SICI)1099-1492(200002)13:1<28::AID-NBM606>3.0.CO;2-L
11. Chiu PW, Mak HKF, Yau KKW, Chan Q, Chang RCC, Chu LW. Metabolic changes in the anterior and posterior cingulate cortices of the normal aging brain: proton magnetic resonance spectroscopy study at 3 T. Age (Dordr) 2014;36:251-64. DOI: https://doi.org/10.1007/s11357-013-9545-8 PMid:23709317 PMCid:PMC3889884
12. Wiedermann D, Schuff N, Matson GB, Soher BJ, Du AT, Maudsley AA, et al. Short echo time multislice proton magnetic resonance spectroscopic imaging in human brain: Metabolite distributions and reliability. MagnReson Imaging 2001;19:1073-80. DOI: https://doi.org/10.1016/S0730-725X(01)00441-6 PMid:11711231
13. Duijn JH, Matson GB, Maudsley AA, Hugg JW, Weiner MW. Human brain infarction: proton MR spectroscopy. Radiology 1992; 183: 711-8. DOI: https://doi.org/10.1148/radiology.183.3.1584925
14. Sutton LN, Wang Z, Gusnard D, Lange B, Perilongo G, Bogdan AR, et al. Proton magnetic resonance spectroscopy of pediatric brain tumors. Neurosurgery 1992;31:195-202. DOI: https://doi.org/10.1227/00006123-199208000-00004 PMid:1513425
15. Alkan A, Kutlu R, Hallac T, Sigirci A, Emul M, Pala N, et al. Occupational prolonged organic solvent exposure in shoemakers: brain MR spectroscopy findings. MagnReson Imaging 2004;22:707-13. DOI: https://doi.org/10.1016/j.mri.2004.01.070 PMid:15172065
16. Harris LM, Davies N, MacPherson L, Foster K, Lateef S, Natarajan K, et al. The use of short-echo-time 1H MRS for childhood cerebellar tumours prior to histopathological diagnosis. PediatrRadiol 2007;37:1101-9. DOI: https://doi.org/10.1007/s00247-007-0571-5 PMid:17823793
17. Schott JM, Frost C, MacManus DG, Ibrahim F, Waldman AD, Fox NC. Short echo time proton magnetic resonance spectroscopy in Alzheimer's disease: a longitudinal multiple time point study. Brain 2010;133:3315-22. DOI: https://doi.org/10.1093/brain/awq208 PMid:20739347 PMCid:PMC2965422
18. Julià-Sapé M, Acosta D, Majós C, Moreno-Torres À, Wesseling P, Acebes JJ, et al. Comparison between neuroimaging classifications and histopathological diagnoses using an international multicenter brain tumor magnetic resonance imaging database. J Neurosurg 2006;105:6-14. DOI: https://doi.org/10.3171/jns.2006.105.1.6 PMid:16874886
19. Guzmán-De-Villoria JA, Mateos-Pérez JM, Fernández-García P, Castro E, Desco M. Added value of advanced over conventional magnetic resonance imaging in grading gliomas and other primary brain tumors. Cancer Imaging 2014;14. DOI: https://doi.org/10.1186/s40644-014-0035-8 PMid:25608821 PMCid:PMC4300038
20. Allen BC, Kapoor S, Anzalone A, Mayer KP, Wolfe SQ, Duncan P, et al. Transcranial ultrasonography to detect intracranial pathology: A systematic review and meta-analysis. J Neuroimaging 2023;33: 333-58. DOI: https://doi.org/10.1111/jon.13087 PMid:36710079
21. Perani D, Della Rosa PA, Cerami C, Gallivanone F, Fallanca F, Vanoli EG, et al. Validation of an optimized SPM procedure for FDG-PET in dementia diagnosis in a clinical setting. Neuroimage Clin 2014;6:445-54. DOI: https://doi.org/10.1016/j.nicl.2014.10.009 PMid:25389519 PMCid:PMC4225527
22. Tomasi D, Shokri-Kojori E, Volkow ND. High-Resolution Functional Connectivity Density: Hub Locations, Sensitivity, Specificity, Reproducibility, and Reliability. Cerebral Cortex 2016;26:3249-59. DOI: https://doi.org/10.1093/cercor/bhv171 PMid:26223259
23. Rizzo R, Kreis R. Multi-echo single-shot spectroscopy combined with simultaneous 2D model fitting for fast and accurate measurement of metabolite-specific concentrations and T2 relaxation times. NMR Biomed 2023;36:e5016. DOI: https://doi.org/10.1002/nbm.5016 PMid:37587062
24. Bartha R. Effect of signal-to-noise ratio and spectral linewidth on metabolite quantification at 4 T. NMR Biomed 2007;20:512-21. DOI: https://doi.org/10.1002/nbm.1122 PMid:17205487
25. Nassirpour S, Chang P, Henning A. High and ultra-high resolution metabolite mapping of the human brain using 1H FID MRSI at 9.4T. Neuroimage 2018;168:211-21. DOI: https://doi.org/10.1016/j.neuroimage.2016.12.065 PMid:28025130
26. Tsai SY, Posse S, Lin YR, Ko CW, Otazo R, Chung HW, et al. Fast mapping of the T2 relaxation time of cerebral metabolites using proton echo-planar spectroscopic imaging (PEPSI). MagnReson Med 2007;57:859-65. DOI: https://doi.org/10.1002/mrm.21225