Application of Magnetic Resonance Imaging Technology in the Detection of Brain Diseases

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Keywords: Functional Magnetic Resonance Imaging (Fmri), Diffusion Tensor Imaging (DTI), Brain Tumor, Cerebral Ischemia, Brain Injury.

Abstract: The brain is the nerve center of human beings which is one of the most important organs of the human body. Once a brain disease occurs, it will bring a heavy blow to the patient, and even endanger the patient's life. At present, brain diseases mainly include brain tumor, brain injury, cerebral ischemia, and so on. Computed tomography (CT) and X-ray photography both have different levels of radiation. In contrast, magnetic resonance imaging (MRI) technology is considered a safe detection method without radiation hazards, so it is suitable for the detection of brain diseases. However, pure MRI has limitations and cannot detect some fine structures or neurological states. Magnetic resonance imaging such as functional magnetic resonance imaging (fMRI) and Diffusion tensor imaging (DTI) can segment brain imaging, detect microbleeds, and judge the state of brain function, and are widely used in the detection of brain diseases. This paper mainly introduces the application of fMRI and DTI in the detection of brain diseases such as brain tumor, brain injury and cerebral ischemia, aiming to provide some ideas for the diagnosis of brain diseases.

1 INTRODUCTION

The brain is the nerve center of human beings which is one of the most important organs of the body. Once a brain disease strikes, it can be a heavy or even devastating blow to the patient. (JIANG, 2011) According to available data, there will be nearly 800 billion euros of brain patients by 2010. (JIANG, 2011) Encephalopathy affects 127 million Europeans, and the annual cost of treatment is €385 billion. (LAWRENCE, 2017) Mental illness accounts for 62% of the cost and neurological disorders, including dementia, for 38%. According to research, brain diseases are more costly than heart disease or cancer. (LAWRENCE, 2017) Also, such a predicament is not unique to Europe and people all over the world are at risk of brain disease. (LIANG, 2020) The brain is the nerve center of the human being, brain damage can lead to a silent, rapidly developing disease that ultimately leads to death. (LIU, 2015) Therefore, diagonalize brain disease has become extremely important.

Brain tumors, damage, ischemia, and other illnesses are all prevalent. Modern diagnostic treatments include Computed tomography (CT), x-rays, and magnetic resonance imaging (MRI). (MACDONALD, 2015) However, there are some brain lesions that may easily be missed with CT examinations. For example, because the lesions are too small or close to the base of the skull, the skull is dense and the resection is too thick, which makes it difficult to diagnose due to "volume effects". (MACDONALD, 2015) In other early-stage disease, including cerebral infarction, the density difference between the lesion and normal brain tissue is significant, making CT difficult to diagnose subacute and chronic intracranial hemorrhage (JIANG, 2011). (PATEL, 2011) X-rays can have diagnostic limitations. For starters, X-rays are 2D pictures, and there is overlap in the diagnosis of brain tissue, making illness localization difficult. (SOTAK, 2002) Then, the brain is mostly soft tissue and fluid, which is absorbed by X-rays, making it impossible to distinguish disease from normal tissue, (UNDERHILL, 2010) but X-rays are superior in determining skull fractures. (VILELA, 2017)

Compared with X-ray, MRI is more effective at detecting brain tumors. It is a cutting-edge, non-invasive technique that generates cross-sectional pictures of the patient's anatomy using magnetic and radio waves. (YUAN, 2004) Therefore, MRI is considered to be a safe detection method without

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radiation hazards. This is due to the fact that MRI uses radiofrequency pulses. This pulse is a long wavelength, low intensity electromagnetic wave that does not damage the body's hydrocarbon bonds. (CAZALIS, 2006) In terms of soft tissue resolution, MRI allows better visibility of the brain's grey matter, nucleus accumbens, nephron cortex and medulla. (CAZALIS, 2006) In addition, MRI can be used in a variety of ways to reflect multi-parametric information about the tissue, including T1 and T2 values, proton density, flux, water molecule diffusion and other parameters. (MACDONALD, 2015) This way of obtaining multiparametric information is not only beneficial for the display of lesions, but also for their qualitative diagnosis. (LAWRENCE, 2017) However, MRI has several limitations. First and foremost, it takes a significant amount of time to picture. Typically, a cranial examination takes about 20 minutes, and a spinal examination takes about 15 minutes. (MCDONALD, 2012) If enhancement is required, the waiting time will be more than 10 minutes. (NARAYANA, 2017) Then, due to the lack of H protons, low-signal calcifications are difficult to detect in MRI pictures, making them insensitive to calcifications. (NARAYANA, 2015) For intramedullary lesions such oedema and tumor invasion, MRI displays high contrast soft tissues but low concentrations of H protons in bone structures. (ROSS, 2011) The most crucial item is that MRI artefacts are more common, as there are numerous contributing elements in MRI imaging. (SHENTON, 2012) Finally, owing to time limits, MRI is not suited for patients in severe condition or with metal implants. (LI, 2020)

This article mainly discusses the use of MRI in the treatment of brain tumors, cerebral ischemia, and brain damage. Then, it makes some reference ideas for diagnosing brain disorders.

2 BRAIN SEGMENTATION METHOD

The two most critical stages in the treatment of brain tumours are segmentation of the brain and identification of the tumour. MRI is a widely used technique for the segmentation and detection of tumours. (WANG, 2017) MRI, which mainly includes fMRI and DTI, can identify the functionality of the brain, especially with increased visualization of the grey and white matter of the brain. (WU, 2020)

FMRI is a neuroimaging detection method. MRI was used to quantify hemodynamic changes induced by neural activity. (AMIN, 2020) Due to its non-invasiveness and minimal radiation exposure, fMRI establishes an important position in the field of functional brain localization. (GUPTA, 2010) In the 1890s, researchers discovered that changes in blood flow and oxygen saturation were intricately linked to neuronal activity. The activation of nerve cells requires oxygen. Oxygen is transported by microvessels near nerve cells using hemoglobin in red blood cells. (GUPTA, 2010) Thus, when a neuron activates, blood flow increases to replenish lost oxygen. There is typically a 1-5 second delay between neural activation and hemodynamic changes, followed by a 4-5 second peak before returning to baseline. (MOHD, 2014) This results in changes in cerebral blood flow not only in areas of neuronal activity but also in local blood deoxyhemoglobin and oxyhemoglobin concentrations and cerebral blood volume. (MYRONENKO, 2019) When subjects are given several types of radioactive chemicals during positron emission tomography (PET) scans, the radioactive chemicals are taken up by activated brain cells. (LAWRENCE, 2017; TIWARI, 2020) MRI uses magnetic fields and radiofrequency radiation to generate pulses of energy in the brain. The pulses may be tuned to certain frequency ranges, inducing atomic couplin. (WADHWA, 2019) When the magnetic pulse is removed, these atoms vibrate and return to their original state. A specialized radio frequency receiver detects these resonances and transmits the information to a computer, which then generates a picture of the location of individual atoms within the brain region. (YANG, 2007) As a result, fMR is more widely used to identify brain disorders.

Magnetic resonance diffusion functional imaging was first introduced by Peter Basser in 1994. (AMIN, 2020) It is an improved version of traditional MRI. DTI uses the diffusion of water as a probe to determine the anatomy of brain networks, providing static anatomical information that is not affected by brain function. (GUPTA, 2010) Because the obstacles along the fibers are relatively small and cannot restrict the movement of water molecules, the water molecules should move faster along the axonal fibers, rather than moving upright toward the fibers. (MOHD, 2014) In axon-based directions, anisotropic diffusion can generate entirely new image contrasts, and this anisotropy is used in DTI to determine the organization of nerve cells in the brain. A 3D diffusion model is estimated by repeating this process in multiple directions. (MYRONENKO, 2019) This approach may result in signal degradation due to diffusing molecules, resulting in darker volumetric pixels or voxels. For instance, white matter fibres running parallel to the magnetic field gradient direction will generate a dark diffusion-weighted picture of that direction. (WADHWA, 2019) The diffusion tensor is then measured by comparing the signal loss to the original signal. The two main parameters to define the orientation of neurons from tensor calculations are fractional anisotropy (FA) and mean diffusivity (MD). (YANG, 2007) FA quantifies the directionality of diffusion, whereas MD quantifies the horizontal average diffusivity. (NARAYANA, 2015) In summary, the above analysis of water diffusion is performed by applying a magnetic field gradient to produce images sensitive to diffusion in a specific direction. A DTI technique is then performed. The DTI technique consists of delivering external magnetic pulses that apply a random phase shift to the diffusing water molecules. And this technique allows for detection and diagnosis. (LI, 2020)

Image processing is another key step in applying MRI to detect tumours. For brain image segmentation, mixed population-learning vector quantization (LVQ) is often employed to find tumour regions in abnormal brain images. (TIWARI, 2020) This approach utilizes Flair, T1C, and T2-weighted imaging, providing an entropy-based strategy. This novel technique employs the formation of reconstruction filters to assist radiologists in rapidly localizing image brightness fluctuations and poorly defined tumour regions. (AMIN, 2020) In addition, LVQ can correct tissue with non-uniform gain and the difficulty of identifying tiny lesions in images. Compared with traditional computer detection systems, 3D magnetic resonance image (MBA) is a semantic segmentation network based on the encoder-decoder structure to segment tumour subregions. (MYRONENKO, 2019) Because brain tumours are relatively difficult to classify, different tumours can exhibit similar appearances, which poses a barrier to traditional computer terminology. (MYRONENKO, 2019) Nonetheless, 3D MRI pictures adhere to the encoder-decoder structure of convolutional neural networks (CNNs) to extract deep visual information through asymmetric large encoders. (MYRONENKO, 2019) The decoder part reconstructs the dense split encoding. At the simultaneous time it adds the variable autoencoder (VAE) branch to the network. In this way the input image can be reconstructed together with the segments, thus normalizing the shared encoder. The method is able to improve the accuracy to about 97%. (TIWARI, 2020)

3 APPLICATION OF MRI IN BRAIN DISEASES

3.1 Application of MRI in the Detection of Brain Tumor

Among the brain segmentation methods described above, FMR and DTI are the most widely used.

FMR is often used for preoperative planning. These results help guide whether to perform surgery, assess risk and prognosis, plan the surgical route, and maximize tumour resection. (GUPTA, 2010) Gupta et al. have demonstrated that FMR imaging mapping of the central sulcus is resistant to potential limiting artefacts from head movement, patient anxiety, and abnormal vasculature. (GUPTA, 2010) Furthermore, since anatomical predictors alone cannot determine whether a specific language region is affected by tumour, FMR is also important in language function and laterality localization. (AMIN, 2020) At the New York Cancer Center, a large proportion of brain tumour patients underwent FMR imaging, mostly preoperative imaging. (MOHD, 2014) This means that a large number of studies underscore the importance of neurosurgeons in obtaining preoperative FMR.

Diffusion-Weighted Imaging (DWI) or DW-MRI is software that generates pictures using a certain magnetic resonance imaging sequence. (WADHWA, 2019) This procedure produces contrast in magnetic resonance pictures by exploiting the diffusion of water molecules. (MOHD, 2014) DTI, a subtype of DWI, has been widely used to map white matter tracts in the brain. (GUPTA, 2010) Traditionally, applying three gradients in one direction is sufficient to determine the "average diffusivity" of the diffusion tensor or trace, a measure of oedema in DWI. (TIWARI, 2020) In clinical practice, trace-weighted images have been shown to be effective in identifying vascular strokes in the brain with early (within minutes) detection of hypoxic oedema. (MYRONENKO, 2019) Furthermore, the principal directions of the diffusion tensor can be used to infer white matter connectivity in the brain. TIWARI This treatment approach is particularly critical in brain tumour surgery, where inadvertent damage to normally functioning white matter pathways can lead to severe neurological damage. (MOHD, 2014).

3.2 MRI Brain Injury Detection Applications

Over the past 30 years, fMRI has been increasingly used to study various neuropsychiatric disorders. But relatively few fMRI studies have examined the cognitive and behavioral sequelae of Mild traumatic brain injury (mTBI), its course over time, and its utility as a biomarker for potential treatments. (WU, 2020) McDonald et al scanned 11 patients with mTBI 1 year after injury to assess changes in brain activation patterns over time. (NARAYANA, 2017) Although at one-year follow-up, the mTBI group no longer reported significant post-concussion sequelae (PCS), they continued to exhibit mild depression in response speed compared to the control group. (LI, 2020) In addition, mTBI patients exhibited task-related increased activation of the right frontal lobe, manifested by the highest white matter (WM) load relative to controls 1 month to 1 year after injury see Figure 1. fMRI in brain injury. (CAZALIS, 2006; MCDONALD, 2012) In both groups, patients showed activation of the left prefrontal cortex over time. This finding suggests that despite the high resolution of PCS, persistent brain dysfunction is still possible 1 year after mTBI. (SHENTON, 2012) McAllister et al. then used fMRI to investigate whether there are problems with episodic memory encoding and retrieval after mTBI. Patients participated in the test, listening to novel and familiar words separately. Results showed increased activation in the right dorsolateral prefrontal cortex (DLPFC) when hearing familiar words. (ROSS, 2011) When new words were heard, the activation of the middle temporal lobe increased. Both the intensity and spatial extent of activation were reduced in mTBI patients compared to controls. (CAZALIS, 2006)

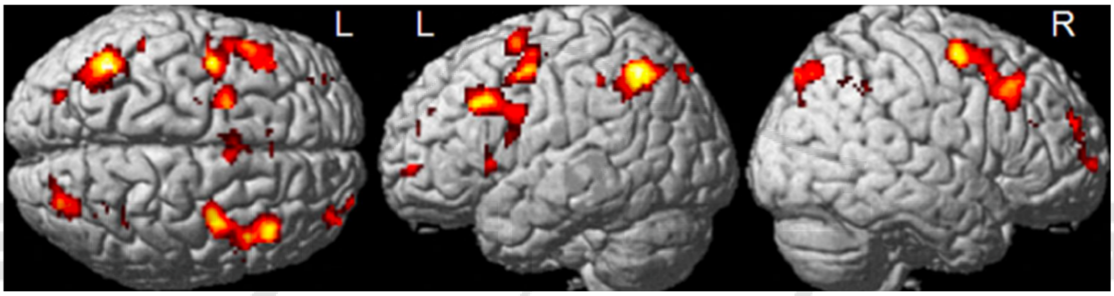

Figure 1. fMRI in brain injury.

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DTI is a sensitive imaging tool for the detection of diffuse axonal injury (DAI) and can be used to detect mild traumatic brain injury (mTBI), also known as concussion. (NARAYANA, 2017) As previously described, DTI is sensitive to subtle changes in white matter fiber tracts and can reveal microstructural axonal damage. Arfanakis used DTI for the first time to study diffuse axonal injury in mTBI, evaluating the two main dependent measures fractional anisotropy (FA) and mean diffusivity (MD) in DTI. (LAWRENCE, 2017) The results showed that there was no difference in MD between mTBI patients and controls. However, researchers observed group differences in the corpus callosum and internal capsule, where FA was reduced in the mTBI group compared to the control group. (CAZALIS, 2006) Importantly, this result was consistent with histopathology. This conclusion makes DTI an important early indicator of brain injury in mTBI. (MCDONALD, 2012) Dr. Alexander Lin et al. used DTI to conclude that repetitive concussions and concussion injuries occur in the etiology of chronic traumatic encephalopathy in sports-related injuries such as professional football. (MCDONALD, 2012) In the report, FA and MD changes were the greatest in one of the athletes. Moreover, the FA and MD of all data changed in both directions of increase and decrease. (MCDONALD, 2012) Johnston et al showed that increased MD and decreased FA may indicate vasogenic edema, which may resolve over time. (NARAYANA, 2017) Whereas an increase in FA and a reduction in MD may imply cytotoxic edoema, which manifests as axonal swelling and more constrained water transport. Thus, higher FA and accompanying reduced MD may suggest a bad prognosis in the early stages of brain damage. (SHENTON, 2012)

3.3 Application of MRI in the Detection of Cerebral Ischemia

Basic physiologic parameters for imaging in acute ischemic stroke include assessment of neuroparenchyma, vascular lumen patency, and ischemic penumbra. (Hakimi, 2019) Thromboembolism in vessels is markedly visualized on susceptibility-weighted imaging (SWI) due to high levels of iron and increased deoxyhemoglobin content in the thrombus. (Hui, 2021) According to clinical experiments, SWI has higher sensitivity and better contrast resolution in detecting thromboembolism in the anterior and posterior circulations. (Hui, 2021) Additionally, SWI is sensitive in identifying the presence of fragmented thrombi and their respective locations. (JIANG, 2011) This is because routine angiography requires the detection of fragmented thrombi in the presence of primary vessel occlusion or poor collateral circulation. (JIANG, 2011) Because SWI is well suited for assessing the intracranial vertebrobasilar circulation, it is critical for assessing thrombus and for neuron Intervention planning. (LAWRENCE, 2017)

DTI is critical in assessing ischemic brain damage. Yang et al. published a preliminary DTI study in experimental stroke and human stroke. DTI, in comparison to other MR measures, gives information on autopsy and geographic evolution of illness. (LIANG, 2020) The unique ability of DTI to differentiate between white and grey matter allows quantitative assessment of ischemic injury in these tissues. Andrew et al. have demonstrated that this feature is useful in explaining spatially heterogeneous changes in water diffusion during the temporal evolution of clinical stroke. (LIU, 2015) In addition, DTI can independently assess the therapeutic response of white and grey matter to neuroprotective therapy. (MACDONALD, 2015) Finally, diffusion anisotropy measurements can be combined with other MR parameters to provide a way to assess cerebral ischemia in a time-independent manner. (PATEL, 2011) This feature is particularly important in a clinical setting because autopsy of stroke onset is often unknown.

4 CONCLUSION

MRI is a good non-invasive means of detection. In addition to the absence of radiation, MRI provides more detailed images than other diagnostic imaging tests, and scans tend to be clearer. (SOTAK, 2002) And allows medical professionals to quickly spot structures or tumors that may be too small to show on an X-ray or CT scan. In particular, it is more widely used in the brain. (YANG, 2007) This article focuses on describing segmentation methods and applications of fMRI and DTI in brain injury, cerebral ischemia, and brain tumors.

With the development of medical imaging technology, magnetic resonance imaging technology has become an important diagnostic tool in clinical neuroradiology, neurology, and neurosurgery today. (MOHD, 2014) Clinically, surgical teams have begun to use fMRI and DTI imaging techniques to plan surgical protocols to minimize the impact on the function of important brain regions. (UNDERHILL, 2010) In addition, with the popularity of magnetic resonance imaging equipment and the improvement of data processing methods, fMRI and DTI have also played a greater role in clinical decision-making. (GUPTA, 2010) Using fMRI to study comatose patients, decisions can be made about the level of consciousness and the probability of recovery in patients with persistent vegetative states. (AMIN, 2020) DTI also provides important value in analyzing the effects of cerebral microbleeds on cognitive impairment and functional impairment. (TIWARI, 2020)

REFERENCES

AMIN, J., SHARIF, M., YASMIN, M. & FERNANDES, S. L. 2020. A distinctive approach in brain tumor detection and classification using MRI. Pattern Recognition Letters, 139, 118-127.

CAZALIS, F., FEYDY, A., VALABREGUE, R., PELEGRINI-ISSAC, M., PIEROT, L. & AZOUVI, P. 2006. fMRI study of problem-solving after severe traumatic brain injury. Brain Inj, 20, 1019-28.

GUPTA, A., SHAH, A., YOUNG, R. J. & HOLODNY, A. I. 2010. Imaging of brain tumors: functional magnetic resonance imaging and diffusion tensor imaging. Neuroimaging Clin N Am, 20, 379-400.

Hakimi, R. and S. Sivakumar, Imaging of Carotid Dissection. Curr Pain Headache Rep, 2019. 23(1): p. 2.

Hui Jia, Z.L., Jun Yuan, Progress in application of high resolution mri in middle cerebral atherosclerosis. 2021.

JIANG, Q., EWING, J. R. & CHOPP, M. 2011. MRI of Blood–Brain Barrier Permeability in Cerebral Ischemia. Translational Stroke Research, 3, 56-64.

LAWRENCE, T. P., PRETORIUS, P. M., EZRA, M., CADOUX-HUDSON, T. & VOETS, N. L. 2017. Early detection of cerebral microbleeds following traumatic brain injury using MRI in the hyper-acute phase. Neurosci Lett, 655, 143-150.

Liang, S., Zhang, J., Zhang, Q., Li, L., Zhang, Y., Jin, T., ZHANG, B., HE, X., CHEN, L., TAO, J., LI, Z., LIU, W. & CHEN, L. 2020. Longitudinal tracing of white matter integrity on diffusion tensor imaging in the chronic cerebral ischemia and acute cerebral ischemia. Brain Res Bull, 154, 135-141.

Liu, C., Li, W., Tong, K. A., Yeom, K. W. & Kuzminski, S. 2015. Susceptibility-weighted imaging and

quantitative susceptibility mapping in the brain. J Magn Reson Imaging, 42, 23-41.
MacDonald, M. E. & Frayne, R. 2015. Cerebrovascular MRI: a review of state-of-the-art approaches, methods and techniques. NMR Biomed, 28, 767-91.
McDonald, B. C., Saykin, A. J. & McAllister, T. W. 2012. Functional MRI of mild traumatic brain injury (mTBI): progress and perspectives from the first decade of studies. Brain Imaging Behav, 6, 193-207.
Mohd. Azhari, E.-E., Mohd. Hatta, M. M., Htike, Z. Z. & WIN, S. L. 2014. Brain Tumor Detection And Localization In Magnetic Resonance Imaging. International Journal of Information Technology Convergence and Services, 4, 1-15.
Myronenko, A. 2019. 3D MRI Brain Tumor Segmentation Using Autoencoder Regularization. Brainlesion: Glioma, Multiple Sclerosis, Stroke and Traumatic Brain Injuries.
Narayana, P. A. 2017. White matter changes in patients with mild traumatic brain injury- MRI perspective.
Narayana, P. A., Yu, X., Hasan, K. M., Wilde, E. A., Levin, H. S., Hunter, J. V., Miller, E. R., Patel, V. K., Robertson, C. S. & McCarthy, J. J. 2015. Multi-modal MRI of mild traumatic brain injury. Neuroimage Clin, 7, 87-97.
Patel, B. & Markus, H. S. 2011. Magnetic resonance imaging in cerebral small vessel disease and its use as a surrogate disease marker. Int J Stroke, 6, 47-59.
Ross, D. E. 2011. Review of longitudinal studies of MRI brain volumetry in patients with traumatic brain injury. Brain Inj, 25, 1271-8.
Shenton, M. E., Hamoda, H. M., Schneiderman, J. S., Bouix, S., Pasternak, O., Rathi, Y., Vu, M. A., Purohit, M. P., Helmer, K., Koerte, I., Lin, A. P., Westin, C. F., Kikinis, R., Kubicki, M., Stern, R. A. & Zafonte, R. 2012. A review of magnetic resonance imaging and diffusion tensor imaging findings in mild traumatic brain injury. Brain Imaging Behav, 6, 137-92.
Shuangxin Li, H. B. 2020. Clinical application and research progress of magnetic resonance diffusion peak imaging (DKI) technique in central nervous system.
Sotak, C. H. 2002. The role of diffusion tensor imaging in the evaluation of ischemic brain injury - a review. NMR Biomed, 15, 561-9.
TIWARI, A., SRIVASTAVA, S. & PANT, M. 2020. Brain tumor segmentation and classification from magnetic resonance images: Review of selected methods from 2014 to 2019. Pattern Recognition Letters, 131, 244-260.
Underhill, H. R., Hatsukami, T. S., Fayad, Z. A., Fuster, V. & Yuan, C. 2010. MRI of carotid atherosclerosis: clinical implications and future directions. Nat Rev Cardiol, 7, 165-73.
Vilela, P. & Rowley, H. A. 2017. Brain ischemia: CT and MRI techniques in acute ischemic stroke. Eur J Radiol, 96, 162-172.
Yuan, C. & Kerwin, W. S. 2004. MRI of atherosclerosis. J Magn Reson Imaging, 19, 710-9.
Wanqian Wang, Q. Y., Kuncheng Li 2017. Clinical application of high resolution magnetic resonance imaging in cerebrovascular diseases.
Wadhwa, A., Bhardwaj, A. & Singh Verma, V. 2019. A review on brain tumor segmentation of MRI images. Magn Reson Imaging, 61, 247-259.
Yalin Wu, J. Y. 2020. Advances in magnetic resonance pH imaging and its application in central nervous system.
Yang, M. S., Lin, K. C., Liu, H. C. & Lirng, J. F. 2007. Magnetic resonance imaging segmentation techniques using batch-type learning vector quantization algorithms. Magn Reson Imaging, 25, 265-77.

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