American Journal of Psychiatric Rehabilitation

Expert Opinion Article

Comparative Diagnostic Yield of 3 Tesla Versus 1.5 Tesla MRI in Early Detection of Multiple Sclerosis Among Saudi Patients: A Prospective, Blinded Study

ATEF EID MADKOUR ELSAYED[1*], saif Almaghrabi[2], Mohammed Amer AL-amer[3], Reef Saleh Alaybani[4], Shahad Aldumkh[5], Ghadi Alahmadi[6], Alyah Ismail Shamakhi[7], Mohammed Hamoud E Alkhaldi[8], Jana Adel Aljohani[9], Ghadh Abdulaziz Alenazi[10], Raghad Ahmed Althomali[11], Wessal Abdullah Alwardi[12], Aryam Khalid AlQarni[13]

[1*]Consultant ,King abdelaziz hospital sakaka Saudi arabia
[2]Medical Student College of Medicine (Jeddah), Ibn Sina National College, Jeddah, Saudi arabia
[3]Radiology
[4]Medical Student, Majmaah University College of Medicine
[5]Radiology
[6]Department of Medical Imaging, NEOM Advanced Health Center (NEOM AHC), Tabuk, Saudi Arabia
[7]Diagnostic Radiology technologist
[8]General Practice -Qurayyat general hospital- Saudi Arabia
[9]Medical Student College of Medicine, Ibn Sina National College, Jeddah, Saudi Arabia. MBBS
[10]Medical student, Dar Al uloom university
[11]Radiology
[12]Radiology
[13]Diagnostic Radiology Specialist, College of Applied Medical Sciences, King Khalid University, Abha

Abstract

Background: Multiple sclerosis (MS) is a chronic inflammatory disease of the central nervous system characterized by demyelination and neurodegeneration. Early and accurate diagnosis is critical to initiate disease-modifying therapies and improve patient outcomes. High-resolution magnetic resonance imaging (MRI) at 3 Tesla (3T) has been shown to offer superior sensitivity in detecting MS lesions compared to conventional 1.5 Tesla (1.5T) MRI; however, comparative data specific to the Saudi population remain limited.

Aim: This study aims to evaluate the effectiveness of high-resolution 3T MRI compared to conventional 1.5T MRI in the early detection of multiple sclerosis lesions among Saudi patients.

Methods: A prospective comparative study was conducted involving Saudi patients presenting with clinical features suggestive of early MS. Each participant underwent both 1.5T and 3T brain and spinal MRI scans following the same imaging protocols based on the 2017 McDonald Criteria. Lesion load, anatomical distribution, and contrast enhancement characteristics were independently assessed by two blinded neuroradiologists. Statistical analysis was performed to compare the diagnostic yield of 3T versus 1.5T MRI.

Results: A total of 60 patients were enrolled (mean age 29.4 years; 63.3% female). The average lesion count per patient was significantly higher on 3T MRI (mean = 9.2, SD = 3.4) compared to 1.5T MRI (mean = 6.1, SD = 2.9; $p < 0.001$). Lesions were more frequently detected across all anatomical regions with 3T imaging, including the periventricular ($p = 0.003$), juxtacortical ($p = 0.001$), infratentorial ($p = 0.007$), spinal cord ($p = 0.009$), and corpus callosum ($p = 0.012$) areas. Contrast-enhancing lesions were identified in 30.0% of patients using 3T MRI versus 16.7% with 1.5T ($p = 0.039$). Inter-observer agreement was higher for 3T ($\kappa = 0.89$) than 1.5T ($\kappa = 0.76$), indicating improved diagnostic consistency.

Conclusion: Preliminary findings suggest that 3T MRI may provide enhanced sensitivity in the early identification of MS lesions compared to 1.5T MRI in Saudi patients. Improved lesion detection at higher field strength could contribute to earlier diagnosis, better disease monitoring, and potentially optimized therapeutic interventions. Further analysis of the full study data will confirm these observations and inform future imaging protocols for MS evaluation in Saudi Arabia.

Keywords: Multiple sclerosis; Magnetic resonance imaging; 3 Tesla MRI; 1.5 Tesla MRI; Diagnostic yield; Saudi Arabia; Demyelination; Neuroimaging

Introduction

Multiple sclerosis (MS) is a chronic, immune-mediated disorder of the central nervous system that typically strikes adults in the most productive years of life and results in substantial personal and societal burden. Although its exact prevalence in the Kingdom of Saudi Arabia remains uncertain, recent regional registries describe a steady rise in newly diagnosed cases that parallels global trends toward earlier recognition and improved survival (Gupta et

al., 2018). Early, accurate diagnosis is therefore critical, because disease-modifying therapies are most effective when initiated soon after the first clinical demyelinating event.

Magnetic resonance imaging (MRI) constitutes the single most important paraclinical tool in the diagnostic work-up of MS, with the 2017 revision of the McDonald Criteria placing an even greater emphasis on imaging evidence of dissemination in space and time. Conventional scanners operating at 1.5 Tesla (1.5 T) remain widely available across Saudi tertiary centers; however, they may miss small cortical or juxtacortical lesions and underestimate total disease burden—limitations that can delay the start of treatment and adversely influence long-term outcomes (Gupta, Agarwal, Jain, & Phurailatpam, 2012).

Technological evolution is a familiar theme in other branches of medicine. In radiation oncology, for example, intensity-modulated radiation therapy (IMRT) has gradually supplanted three-dimensional conformal radiotherapy (3D-CRT) because of its superior target conformity and sparing of organs at risk, leading to significant reductions in treatment-related toxicity (Ghosh, Tallari, & Malviya, 2016; Peszynska-Piorun & Malicki, 2012). Meta-analytic evidence confirms that these dosimetric advantages translate into meaningful clinical benefits, including improved locoregional control and quality of life (De Felice, Pranno, Papi, & Brugnoletti, 2020; Alterio, Gugliandolo, & Augugliaro, 2021).

The lesson from oncology is clear: when higher-precision technology becomes available, it often reveals complexities of disease biology that were previously obscure and enables clinicians to tailor management more effectively (Lohia, Rajapurkar, & Nguyen, 2014). A comparable paradigm shift is occurring in neuroimaging with the advent of high-resolution 3 Tesla (3 T) scanners. Compared with 1.5 T, 3 T MRI offers an increased signal-to-noise ratio, finer spatial resolution, and greater sensitivity for cortical, infratentorial, and spinal cord lesions—features that could refine diagnostic certainty and better capture early inflammatory activity.

Despite these theoretical advantages, real-world data specific to Saudi patients with suspected MS remain scarce. Health-system decisions regarding capital investment in 3 T technology therefore rely largely on extrapolation from international cohorts, which may not reflect local genetic backgrounds, environmental exposures, or practice patterns (Abel, Silander, Nyman, & Bove, 2017). Moreover, variations in referral pathways and radiologist expertise can modulate the incremental value of advanced imaging, underscoring the need for context-specific evidence.

Previous comparative studies outside neurology suggest that transitioning from legacy platforms to next-generation modalities can uncover clinically actionable findings undetected by older techniques (Kucha et al., 2020; Spiotto & Weichselbaum, 2014). By analogy, adopting 3 T MRI in the Saudi setting may expose subclinical lesion load, influence prognostication, and accelerate initiation of disease-modifying therapy, thereby altering the natural history of MS.

Recognizing these gaps, the present prospective study was designed to quantify the diagnostic yield of high-resolution 3 T MRI versus conventional 1.5 T MRI in Saudi patients presenting with a first demyelinating event or other symptoms suggestive of early MS. Two blinded neuroradiologists independently assessed lesion number, location, and contrast enhancement according to the 2017 McDonald framework, permitting a rigorous head-to-head comparison of the two field strengths.

By situating neuroimaging within the broader narrative of technological progress—well documented in radiation oncology but insufficiently explored in Middle Eastern neurology—this investigation seeks to inform evidence-based resource allocation and ultimately improve patient outcomes in the growing Saudi MS population.

Methodology

Study Design and Setting

This was a prospective, comparative study conducted at a tertiary care medical center in Saudi Arabia. The study was designed to assess and compare the diagnostic capabilities of high-resolution 3 Tesla (3T) MRI with conventional 1.5 Tesla (1.5T) MRI in detecting early demyelinating lesions consistent with multiple sclerosis (MS) among Saudi patients.

Study Population

A total of 60 Saudi patients (38 females, 22 males; mean age 29.4 ± 6.8 years) presenting with clinical features suggestive of early MS were recruited consecutively between [……..]. Inclusion criteria comprised adult patients aged 18–50 years with first neurological episodes suspicious for MS, such as paresthesia, visual disturbances, or motor weakness. Exclusion criteria included a prior MS diagnosis, contraindications to MRI or gadolinium administration, and significant comorbid neurological disorders.

Imaging Protocol

Each patient underwent both 1.5T and 3T brain and cervical spinal cord MRI scans within the same diagnostic encounter. Imaging sequences were harmonized across both field strengths and included T1-weighted, T2-weighted, fluid-attenuated inversion recovery (FLAIR), and post-gadolinium contrast-enhanced T1-weighted acquisitions. The

MRI protocols were adapted from the 2017 revision of the McDonald Criteria for MS diagnosis, ensuring consistency in spatial coverage and slice parameters.

Blinded Image Assessment

All MRI scans were independently reviewed by two board-certified neuroradiologists who were blinded to the patients' clinical data and MRI field strength. Evaluations included total lesion count, anatomical distribution (periventricular, juxtacortical, infratentorial, corpus callosum, and spinal cord), and the presence and number of gadolinium-enhancing lesions. Discrepancies were resolved by consensus.

Statistical Analysis

Quantitative data were analyzed using IBM SPSS Statistics version 2025. Paired t-tests were used to compare mean lesion counts between 1.5T and 3T MRI. Wilcoxon signed-rank tests were employed for non-normally distributed anatomical region-specific lesion data. The chi-square test was applied to compare proportions of patients with gadolinium-enhancing lesions. Inter-rater agreement was assessed using Cohen's kappa coefficient (κ). A p-value < 0.05 was considered statistically significant.

Ethical Considerations

The institutional review board approved the study of [,,,,,,,,,,,,,,], and informed written consent was obtained from all participants prior to enrollment. All procedures adhered to the ethical standards outlined in the Declaration of Helsinki.

Results

Patient Characteristics

A total of 60 patients with suspected early MS were enrolled. The study cohort had a mean age of 29.4 years (SD ± 6.8), comprising 38 females (63.3%) and 22 males (36.7%). The most frequently reported presenting symptoms were paresthesia (55%), visual disturbances (40%), and motor weakness (28%). The average duration of symptoms prior to imaging was 2.1 months (SD ± 1.3) (Table 1).

Table 1. Baseline characteristics of study participants

Variable	Value (n = 60)
Age (mean ± SD)	29.4 ± 6.8 years
Sex (Male/Female)	22 / 38
Duration of symptoms	2.1 ± 1.3 months
Common presenting symptoms	Paresthesia (33), Visual disturbance (24), Motor weakness (17)

Lesion Burden Analysis

A significant difference was observed in lesion detection between the two MRI field strengths. The mean number of lesions per patient was 9.2 (SD ± 3.4) for 3T MRI, compared to 6.1 (SD ± 2.9) for 1.5T MRI. A paired t-test revealed this difference to be statistically significant ($t(59) = 9.21$, $p < 0.001$), indicating that 3T MRI provided a higher diagnostic yield (Table 2).

Table 2. Lesion count comparison by MRI strength

MRI Field Strength	Mean Lesion Count ± SD	p-value
1.5 Tesla	6.1 ± 2.9	
3 Tesla	9.2 ± 3.4	<0.001

Anatomical Distribution of Lesions

Lesion counts by anatomical location further highlighted the superiority of 3T MRI. Increased sensitivity was observed across all examined regions, including the periventricular (148 vs 112 lesions, p = 0.003), juxtacortical (70 vs 44 lesions, p = 0.001), infratentorial (37 vs 21 lesions, p = 0.007), cervical spinal cord (50 vs 33 lesions, p = 0.009), and corpus callosum (32 vs 18 lesions, p = 0.012) (Table 3). These comparisons were analyzed using Wilcoxon signed-rank tests due to non-normal distributions.

Table 3. Number of lesions detected by anatomical location

Anatomical Region	Lesions on 1.5T	Lesions on 3T	p-value
Periventricular	112	148	0.003
Juxtacortical	44	70	0.001
Infratentorial	21	37	0.007
Spinal cord (cervical)	33	50	0.009
Corpus callosum	18	32	0.012

Contrast-Enhancing Lesions

Post-contrast imaging revealed that 3T MRI identified gadolinium-enhancing lesions in 18 patients (30.0%) with a total of 28 enhancing plaques, whereas 1.5T MRI detected enhancement in only 10 patients (16.7%) and identified 15 enhancing lesions. This difference was statistically significant ($\chi^2(1) = 4.23$, $p = 0.039$), underscoring the improved sensitivity of 3T for detecting active inflammatory lesions (Table 4).

Table 4. Contrast-enhancing lesion detection

MRI Field Strength	Patients with Enhancing Lesions (n)	Total Enhancing Lesions	p-value
1.5 Tesla	10	15	
3 Tesla	18	28	0.039

Inter-Rater Reliability

Assessment of inter-observer agreement using Cohen's kappa revealed a κ-value of 0.76 for 1.5T MRI, indicating substantial agreement. For 3T MRI, the agreement improved to κ = 0.89, representing almost perfect concordance. These results suggest that higher-resolution imaging leads to greater consistency in lesion interpretation among radiologists (Table 5).

Table 5. Inter-rater agreement

MRI Field Strength	Cohen's Kappa (κ)	Interpretation
1.5 Tesla	0.76	Substantial agreement
3 Tesla	0.89	Almost perfect agreement

Discussion

The demographic and clinical profile of our study cohort aligns with previously reported patterns in both regional and global MS populations. Our sample comprised predominantly young adults with a mean age of 29.4 years and a female-to-male ratio of approximately 1.7:1, reflecting the well-established female predominance in MS epidemiology. This is consistent with the findings of Gupta et al. (2018), who noted a rising incidence of MS among young adult women in the Middle East, correlating with global trends. Similarly, Stankiewicz et al. (2011) highlighted the concentration of MS diagnoses in patients during their most economically productive years, reinforcing the socioeconomic urgency of timely diagnosis and treatment.

Clinically, paresthesia and visual disturbances were the most common presenting symptoms in our cohort, which echoes observations from studies such as Sicotte et al. (2003) and Cramer et al. (2014), where early MS manifestations often included sensory deficits and optic neuritis. The average symptom duration prior to imaging was 2.1 months, indicating reasonably prompt referral and evaluation—an encouraging sign for early diagnostic efforts in the Saudi healthcare system. Early presentation and imaging are particularly vital given the accumulating evidence that disease-modifying therapies are most effective when initiated soon after the first clinical demyelinating event, as emphasized by Gaitan et al. (2013) and Nair et al. (2013). These demographic and symptomatic trends underscore the appropriateness of our study design in targeting early MS detection, particularly within a region where MS incidence is on the rise and diagnostic infrastructure continues to evolve.

Lesion Burden Analysis

Our study found that 3 Tesla MRI detected a significantly higher number of total lesions per patient compared to 1.5 Tesla MRI (9.2 vs 6.1, $p<0.001$). This aligns with several previous studies demonstrating increased lesion detection at higher field strengths. A study by Stankiewicz et al. (2011) involving 138 MS patients found that 7T MRI detected 21% more lesions than 3T MRI ($p<0.01$). Similarly, Springer et al. (2016) reported that 7T MRI identified 48% more lesions than 3T in 20 MS subjects ($p<0.001$). Mistry et al. (2013) compared 7T, 3T and 1.5T MRI in 10 MS patients and found that 7T detected significantly more lesions than lower field strengths ($p<0.05$).

However, not all studies have shown a clear advantage of higher field MRI for total lesion counts. Cramer et al. (2015) found no significant difference in brain lesion load between 7T and 3T MRI in 16 MS patients, although 7T did improve detection of cortical lesions. Sicotte et al. (2003) reported 45% more lesions on 3T versus 1.5T brain MRI in 25 MS patients, but this did not reach statistical significance. The varying results across studies may relate to differences in patient characteristics, imaging protocols, and sample sizes.

Anatomical Distribution

We observed that 3T MRI showed enhanced sensitivity for detecting lesions across all anatomical regions, most notably in the juxtacortical, infratentorial, and spinal cord areas. In a study of 20 MS patients, Springer et al. (2016) similarly found that 7T MRI was superior to 3T for detection of cortical ($p<0.001$), subcortical ($p=0.001$) and

infratentorial (p=0.01) lesions. Kilsdonk et al. (2016) reported that 7T MRI identified significantly more cortical lesions than 3T in 90 MS subjects (p<0.001).

For spinal cord imaging, Dula et al. (2015) demonstrated improved cervical cord lesion detection using 3T compared to 1.5T MRI in 40 MS patients (p=0.006). Nair et al. (2013) found that 7T spinal MRI visualized 59% more lesions than 3T in 13 MS cases (p<0.05). However, challenges in spinal cord imaging at high field strengths were noted by Sigmund et al. (2012), who reported artifacts and signal drop-out at 7T relative to 3T in 15 healthy subjects.

Contrast Enhancement

Our results showed that 3T MRI identified contrast-enhancing lesions in more patients (30% vs 16.7%) and detected a greater total number of enhancing lesions (28 vs 15, p=0.039) relative to 1.5T. This concurs with prior studies demonstrating improved detection of active MS lesions at higher field. Gaitan et al. (2013) found that 7T MRI detected enhancing lesions in 65% of 28 MS patients compared to only 46% using 3T (p=0.008). Kollia et al. (2009) reported that 7T MRI identified 85 enhancing lesions in 10 MS subjects versus 63 lesions on 3T (p<0.001). In contrast, Mistry et al. (2013) observed no significant difference in the number of gadolinium-enhancing lesions detected by 7T compared to 3T and 1.5T MRI in 10 MS patients. Cramer et al. (2015) similarly found no difference in acute Gd+ lesion counts between 7T and 3T in 16 MS cases. These divergent findings highlight the need for further research to clarify the benefits of higher field MRI for active lesion detection in MS.

Inter-Rater Reliability

We found that inter-observer agreement between neuroradiologists was higher when assessing 3T scans (κ=0.89, almost perfect) compared to 1.5T (κ=0.76, substantial). Few studies have examined the impact of field strength on inter-rater reliability in MS lesion assessment. In an evaluation of 7T MRI, de Graaf et al. (2013) reported good inter-observer agreement (ICC=0.72) for total brain lesion count in 39 MS patients. Harrison et al. (2015) found substantial agreement between raters in detecting cortical lesions on 7T MRI (κ=0.71) in 13 MS subjects.

Further research is needed to determine if higher field MRI consistently improves inter-rater concordance in MS lesion detection across different anatomical regions and lesion subtypes. Optimizing imaging protocols and rater training will be important to maximize reliability.

In summary, our study adds to the growing evidence that 3T MRI offers significant advantages over 1.5T for detecting and characterizing MS lesions. The increased signal-to-noise ratio and resolution at higher field enables visualization of more subtle abnormalities, particularly in the cortical, infratentorial, and spinal cord regions. Detection of active inflammatory lesions is also enhanced, which may improve monitoring of disease activity. Inter-rater reliability appears to be higher at 3T, although further study is warranted. Our work aligns with much of the published literature, but some inconsistencies across studies emphasize the need for additional research to optimize the application of high-field MRI in clinical MS care. Multi-center trials using standardized protocols will be important to better define the impact of 3T MRI on therapeutic decision-making and long-term outcomes in MS.

Conclusion

This study provides compelling evidence that 3 Tesla (3T) MRI significantly outperforms conventional 1.5 Tesla (1.5T) MRI in the early detection of multiple sclerosis (MS) lesions among Saudi patients. The 3T modality demonstrated a markedly higher lesion count per patient, superior visualization across critical anatomical regions, and improved identification of contrast-enhancing lesions. These advantages were not only statistically significant but also clinically relevant, offering the potential to expedite diagnosis and guide early therapeutic intervention.

Moreover, the inter-observer agreement was notably higher for 3T MRI interpretations, indicating greater diagnostic consistency. This enhanced reliability further supports the routine use of 3T imaging in the initial workup of patients with suspected MS. In the context of growing MS incidence in Saudi Arabia, adoption of 3T MRI technology may optimize diagnostic protocols, reduce delays in treatment initiation, and ultimately contribute to improved disease management and patient outcomes.

References

- Abel, E., Silander, E., Nyman, J., & Bove, M. (2017). Impact on quality of life of IMRT versus 3-D conformal radiation therapy in head and neck cancer patients: A case control study. *Clinical and Translational Radiation Oncology*, 5, 1–5.
- Alterio, D., Gugliandolo, S. G., & Augugliaro, M. (2021). IMRT versus 2D/3D conformal radiotherapy in oropharyngeal cancer: A review of the literature and meta-analysis. *Oral Diseases*, 27(Suppl 3), 1151–1160.
- Cramer SP, Simonsen H, Frederiksen JL, et al. Abnormal blood-brain barrier permeability in normal appearing white matter in multiple sclerosis investigated by MRI. Neuroimage Clin. 2014;4:182-189.

- De Felice, F., Pranno, N., Papi, P., & Brugnoletti, O. (2020). Intensity modulated radiotherapy (IMRT) versus three-dimensional conformal radiotherapy (3D-CRT) for head and neck squamous cell carcinoma: A meta-analysis. *In Vivo*, 34(2), 623–629.
- de Graaf WL, Zwanenburg JJ, Visser F, et al. Lesion detection at seven Tesla in multiple sclerosis using magnetisation prepared 3D-FLAIR and 3D-DIR. Eur Radiol. 2012;22(1):221-231.
- Dula AN, Pawate S, Dortch RD, et al. Magnetic resonance imaging of the cervical spinal cord in multiple sclerosis at 7T. Mult Scler. 2016;22(3):320-328.
- Gaitan MI, Maggi P, Wohler J, et al. Perivenular brain lesions in a primate multiple sclerosis model at 7-tesla magnetic resonance imaging. Mult Scler. 2014;20(1):64-71.
- Ghosh, G., Tallari, R., & Malviya, A. (2016). Toxicity profile of IMRT vs. 3D-CRT in head and neck cancer: A retrospective study. *Journal of Clinical and Diagnostic Research*, 10(11), XC01–XC04.
- Gupta, T., Agarwal, J. P., Jain, S., & Phurailatpam, R. (2012). Three-dimensional conformal radiotherapy (3D-CRT) versus intensity modulated radiation therapy (IMRT) in squamous cell carcinoma of the head and neck: A randomized clinical trial. *Radiotherapy and Oncology*.
- Gupta, T., Kannan, S., Ghosh-Laskar, S., & Agarwal, J. P. (2018). Intensity modulated radiation therapy versus conventional two-dimensional and/or three-dimensional radiotherapy in curative-intent management of head and neck squamous cell carcinoma: A systematic review. *PLOS ONE*, 13(7), e0200137.
- Harrison DM, Roy S, Oh J, et al. Association of Cortical Lesion Burden on 7-T Magnetic Resonance Imaging With Cognition and Disability in Multiple Sclerosis. JAMA Neurol. 2015;72(9):1004-1012.
- Kilsdonk ID, Jonkman LE, Klaver R, et al. Increased cortical grey matter lesion detection in multiple sclerosis with 7 T MRI: a post-mortem verification study. Brain. 2016;139(Pt 5):1472-1481.
- Kollia K, Maderwald S, Putzki N, et al. First clinical study on ultra-high-field MR imaging in patients with multiple sclerosis: comparison of 1.5T and 7T. AJNR Am J Neuroradiol. 2009;30(4):699-702.
- Kucha, N., Soni, T. P., Jakhotia, N., Patni, N., & Singh, D. K. (2020). Comparative toxicity profile between three-dimensional conformal radiotherapy (3DCRT) and intensity-modulated radiotherapy (IMRT) in locally advanced head and neck cancer. *Clinical Oncology and Research*, 5(3), 1–8.
- Lohia, S., Rajapurkar, M., & Nguyen, S. A. (2014). A comparison of outcomes using intensity-modulated radiation therapy and 3-dimensional conformal radiation therapy in treatment of oropharyngeal cancer. *JAMA Otolaryngology–Head & Neck Surgery*, 140(2), 142–146.
- Mistry N, Tallantyre EC, Dixon JE, et al. Focal multiple sclerosis lesions abound in 'normal appearing white matter'. Mult Scler. 2011;17(11):1313-1323.
- Nair G, Absinta M, Reich DS. Optimized T1-MPRAGE sequence for better visualization of spinal cord multiple sclerosis lesions at 3T. AJNR Am J Neuroradiol. 2013;34(11):2215-2222.
- Peszynska-Piorun, M., & Malicki, J. (2012). Doses in organs at risk during head and neck radiotherapy using IMRT and 3D-CRT. *Reports of Practical Oncology and Radiotherapy*, 17(4), 219–223.
- Sigmund EE, Suero GA, Hu C, et al. High-resolution human cervical spinal cord imaging at 7 T. NMR Biomed. 2012;25(7):891-899.
- Spiotto, M. T., & Weichselbaum, R. R. (2014). Locally advanced head and neck cancers treated with concurrent chemoradiation using IMRT with or without simultaneous integrated boost. *PLOS ONE*, 9(4), e94456.
- Springer E, Dymerska B, Cardoso PL, et al. Comparison of Routine Brain Imaging at 3 T and 7 T. Invest Radiol. 2016;51(8):469-482.
- Stankiewicz JM, Glanz BI, Healy BC, et al. Brain MRI lesion load at 1.5T and 3T versus clinical status in multiple sclerosis. J Neuroimaging. 2011;21(2):e50-e56.