Table 2

Overview of 1.5T and 3T MRI longitudinal studies

FIELD	ID	DATE	REFERENCE	SS	GA	MRI-TEA SEQUENCES	MRI SCORING MODEL	FOCUS	CA (MONTHS)	LONGITUDINAL ASSESSMENT	FINDINGS
1.5T MRI	1	2004	(Mirmiran et al., 2004)	61	EP VP	T1-W SE, T2-W FSE, FLAIR, GRE	Scores abnormal intensities (e.g. CSF, unmyelinated), structural alterations (e.g. WM and GM), and ventricular size and configuration	Cognitive, language, motor, social-emotional and adaptive functions	31	BSID-II	Predictor of CP (86% ss; 89% sp)
	2	2005	(Woodward et al., 2005)	100	EP VP	3D SPGR, T2-W DE	Inder et al. (2003)	Memory- and cognitive, language, motor, social-emotional and adaptive functions	24	MSML and BSID-II	No significant associations were found with CSF volumes, WM, CGM and dGM.
	3	2012	(Skiöld et al., 2012)	91	EP	T1-W SE, T2-W TSE, T2* TSE, T2*-W FFE, FLAIR, 3D T1-W GE	Inder et al. (2003)	Cognitive, language, motor, social-emotional and adaptive functions	30	BSID-III	Moderate-severe WMI and CP (50% ss; 97,5% sp). Cystic changes, delayed myelination and severe white matter reduction were found to be associated with CP. Isolated dilatation of lateral ventricles and subarachnodial space were not associated with CP.
	4	2013	(Skiöld et al., 2013)	53	EP	T1-W and T2-W	Inder et al. (2003)	Cognitive, language, motor, social-emotional and adaptive functions	30	BSID-III	Moderate-severe WMI highly predict CP (100% ss; 98% sp). No associations with GM abnormalities.
	5	2019	(Skiöld et al., 2019)	66	EP	T1-W and T2-W	Inder et al. (2003)	Cognitive , fine motor, and gross motor ability	30	BSITD-III	Moderate-severe WMI associated with CP (75% ss; 97% sp) and with severe cognitive delay (100% ss; 95% sp). Other not significant associated. Individual scoring items showed WM reduction, delayed myelination and cysts which are associated with unspecific neurological signs, CP and severe cognitive delay. Abnormal signal in cGM or dGM was associated with severe cognitive delay.

	6	2019	(Burkitt et al., 2019)	57	EP	T1-W, T2W-I, FLAIR, SWI, DWI, 3D T1-W	Leijser et al. (2018)	Cognitive, language, motor, social-emotional and adaptive functions	36	BSID-III	All grades of WMI on MRI poorly predict abnormal neurodevelopmental outcome (Grade 1: 7.1% ss, 81.8% sp; Grade 2: 7.1% ss, 90.9% sp; Grade 3: 14.3% ss, 97.7% sp). Absence of an injury on MRI did not predict normal outcome.
	7	2020	(van Gils et al., 2020)	112	EP VP	T1-W and T2-W	Kidokoro et al. (2013)	Visio-spatial attention and processing	24	Eye tracking assessment	There are no significant correlations between different reaction times and global, cerebral WM, CGM, DGM injuries.
	8	2020	(Haebich et al., 2020)	159	EP VP	T1-W and T2-W	Kidokoro et al. (2013)	Goal setting	312	DKEFS, RCFT and BADS-C	WM, DGW and cerebellum abnormality scores were associated with poorer goal setting abilities. Association between CGM abnormality and poorer goal setting scores was weaker. There was also evidence that greater cerebellum, thalamus and cGM volumes were associated with better goal setting performances.
	9	2021	(Brembilla et al., 2021)	72	EP VP	T1-W and T2-W, DWI	TMS scale and 2D area determination	Cognitive, language, motor, social-emotional and adaptive functions	24 and 36	GMDS and BSID-III	Positive correlation between the parenchyma area and the cognitive score (r= 0.33, p=0.019). Weak significant correlation between median cognitive score and GA (r= 0.32,p=0.024). Multivariate analysis confirmed the associations between decreased parenchyma areas and worse cognitive scores (p=0.0014).
	10	2022	(Sheng et al., 2022)	178	EP VP	3D T1-W-I, DTI, MRS	Guo et al. (2017), Papile et al. (1978)	Cognitive outcome and motor skills	54	WPPSI-III, MABC-II	Larger ventricular volume are associated with lower motor scores. Ventricular volume and FA in several white matter tracts (genu, splenium, optic radiations, and PLIC) and in the lentiform nucleus and thalamus. Ventricular volume was associated with mean diffusivity in the splenium, PLIC, and optic radiations. Significant associations between ventricular volume and radial diffusivity in the genu, splenium, optic radiations, and thalamus were observed as well. No significant association between ventricular volume and NAA/choline was observed

3T MRI	1	2017	(Brouwer et al., 2017)	239	EP	3D T1-W, T2-W	Kidokoro et al. (2013)	Cognitive , fine motor, and gross motor ability	24 or 30	BSITD-III	The global brain abnormality score was inversely poor related to cognitive and motor outcome. A negative association was observed between cognition and cerebellar abnormalities. Fine motor outcome was related to WM injury, whereas gross motor outcome was associated with both WM and deep GM injury. WM abnormalities have previously been related to motor impairments. Regarding the brain metrics in corporate in the TEA-MRI score, associations with cognitive and motor performance were exclusively observed for ventricular and cerebellar measurements.
	2	2018	(Vesoulis et al., 2018)	154	EP	T1-W and T2-W, SWI	Papile et al. (1978)	Cognitive, language, motor, social-emotional and adaptive functions	24	BSID-III	When the imaging score (CH score+ IVH score + WMI score) was added to the “slim” clinical model, the composite model was strongly predictive of severe neurodevelopmental outcome (76% ss; 90% sp).
	3	2019	(Strahle et al., 2019)	158	EP VP	T2-W	Papile et al. (1978)	Memory function of hippocampus	24	BSITD-III	Larger neonatal hippocampal volumes were associated with better motor outcomes
	4	2020	(Hammerl et al., 2020)	237	EP VP	T1-W, 3D MPRAGE T1-W, SWI	BPW, ECS, IHD	Cognitive, language, motor, social-emotional and adaptive functions	24	BSID-II en BSITD-III (MDI and PDI)	A normal BPW predicts normal psychomotor outcome in 94.4% of infants. Having all brain metrics within the normal range predicts normal psychomotor outcome in 96.6% of infants and normal cognitive outcome in 86.2%. Having an enlargement of IHD and simultaneously a BPW z-score less than –0.5 predicts developmental delay in 58.3% of children and predicts cognitive delay (50%) better than psychomotor delay (33.3%)
	5	2020	(Storbeck et al., 2020)	73	EP VP	T2-W SE, 3D T1-W FLASH, SWI, DWI	Volumetric analysis of DGM (basal ganglia and thalamus), and ventricles to estimate white matter los	Influence of asymmetry of brain structures on handedness and MDI/PDI	24	BSID-II	Correlation of total DGM volume with MDI and PDI. Impaired development of DGMs observed following prematurity. Preterm infants with altered development of DGM showed neurodevelopmental disability and visual impairment

	6	2020	(Kostović Srzentić et al., 2020)	21	EP	T1-W SE, T2-W FSE, T2-W PD and 3D GRE and T1 MPRAGE	Lateral ventricles dilatation, changes in signal intensity and reduction of WM	general and specific cognitive abilities (IQ, VIQ, PIQ). Executive functioning, language, memory, sensorimotor and visuospatial processing	36-60	WPPSI-III, NEPSY-II	WM reduction in the parietal and occipital lobes was related to IQ scores. Ventricular enlargement was negatively related to IQ scores. Cortical thickness showed positive correlation with IQ scores in frontal, occipital, parietal and limbic lobes. Cerebrospinal volume was negatively related to IQ and PIQ. Insular volume was positively related to PIQ. WM reduction in the parietal, temporal and occipital lobes was related to executive functions, language, visuo-motor and visuo-spatial tasks. Ventricular enlargement in the frontal, temporal and occipital lobes related to most cognitive functions. Cortical thickness in the frontal lobe was related to specific cognitive functions. A positive correlation was found between thickness of the parietal, temporal, occipital, limbic and insular lobes and narrative memory, visuo-spatial and visuo-motor functions. Cerebrospinal fluid volume was negatively related to visuo-motor precision. Insular volume was positively related to visuo-spatial tasks. Other measurements at TEA MRI were not related to cognitive scores.
	7	2020	(Parikh, He, et al., 2020)	74	EP VP	T2W-I, 3D T1 MPRAGE, SWI	DWMA volume calculation and Kidokoro et al. (2013) classifications	Cognitive, language, motor, social-emotional and adaptive functions	24	BSITD-III	Moderate-severe DWMA significantly predicted cognitive impairments but not language impairments. Severe DWMA predicted cognitive impairments at age 2 (100.0% ss; 95.7% sp). In comparison, moderate injury on structural MRI exhibited lower predictive value for cognitive impairments and visually-diagnosed severe DWMA did not significantly predict cognitive or language impairments. Combining visually-diagnosed, moderate-severe grades of DWMA did not improve prediction of cognitive or language impairments.

8	2020	(Parikh, Harpster, et al., 2020)	77	EP VP	T2W-I, 3D T1 MPRAGE, SWI	DWMA volume calculation and Kidokoro et al. (2013) classifications	Cognitive, language, motor, social-emotional and adaptive functions	36	BSITD-III	The relationship between DWMA volume and CP remained significant after controlling for global brain abnormality, GA, and center. Conversely, we did not find a significant relationship between qualitatively diagnosed DWMA and CP. Objectively quantified severe DWMA and global brain abnormality on structural MRI were both significantly predictive of CP, while visually-classified severe DWMA was a poor predictor of CP.
9	2021	(Logan et al., 2021).	110	EP VP	T2W-I, 3D T1 MPRAGE, SWI	dHCP and Kidokoro et al. (2013)	Cognitive, language, motor subtests	24	BSID-III	While surface area, sulcal depth and global injury score were associated with developmental scores. Only surface area and global injury score remained significantly associated with developmental scores. Even after adjusting for confounders, surface area and global injury risk score were significantly associated with neurodevelopmental outcomes. Roughly 70% of the relationship between CRIB-II and cognitive impairments was mediated by our composite MRI risk score, global injury score. The mediating effects of the global injury score also accounted for roughly 40% of the effects of the relationship between CRIB-II and Bayley language scores. Moreover, approximately 87% of the effects of illness-severity on motor scores was mediated through the global injury score, and roughly 50% through cortical surface area.
10	2021	(Mayock et al., 2021)	178	EP	T1-W and T2-W	Papile et al. (1978) and Kidokoro et al. (2013)	Cognitive, language, motor, social-emotional and adaptive functions	24	BSITD-III	Increasing WMI score was associated with larger reductions in motor function, cognitive ability and language skills. An association between cerebellum injury scores and BSID-III motor scores was observed, but was attenuated for cognitive ability and language skills.

1.5T AND 3T MRI	1	2019	(Dewan et al., 2019)	129	EP	T1-W and T2-W	Brain growth metrics (BPW, IDH, TCD) and Kidokoro et al. (2013)	MDI and PDI	24	BSID-II	Significant correlation between BPW and PDI. IHD was not significantly correlated with MDI or PDI. TCD significantly correlated with MDI and PDI. There was no association between WMI and MDI. WMI= 5 was significantly associated with decreased PDI. Higher scores were not associated with PDI.
	2	2022	(Goeral et al., 2022)	103	EP VP	T2W-I TSE, DWI, T1W-I SE	Three domains: GM, WM and total MRI score	Cognitive and motor abilities	24-36	BSID-II/I and GMFCS	The R2 for total MRI score was 0.65 for cognitive outcome and 0.81 for motor outcome. The R2 for all sub scores was 0.56/0.68/0.74 (grey matter score/white matter score/additional points) for cognitive and 0.75/0.82/0.86 (grey matter score/white matter score/additional points) for motor outcome. Receiver operating curves demonstrated that total MRI score could differentiate between favourable and unfavourable outcomes, with a high area under the curve of 0.78 for cognitive, 0.84 for motor outcome, and 0.94 for CP. Compared with the conventional IVH grading based on CUS, area under the curve of total MRI score were significantly higher by 0.16 for cognitive, 0.17 for motor outcome, and 0.15 for CP.
	3	2022	(Ayed et al., 2022)	146	EP VP	T1-W, T2-W, DWI	Papile et al. (1978) and Miller scoring	Cognitive and motor abilities in MgSO4 treated neonates	36	BSID-III	Antenatal MgSO4 exposure is associated with significantly greater odds of better motor BSID score and better cognitive score.

References

Ayed, M., Ahmed, J., More, K., Ayed, A., Husain, H., AlQurashi, A., & Alrajaan, N. (2022). Antenatal Magnesium Sulfate for Preterm Neuroprotection: A Single-Center Experience from Kuwait Tertiary NICU. *Biomedicine Hub*, *7*(2), 80–87. https://doi.org/10.1159/000525431

Brembilla, G., Righini, A., Scelsa, B., Lista, G., Balestriero, M., Cesari, E., Castoldi, F. M., di Stasi, M., Ciardi, C., Ligato, E., Taricco, E., & Cetin, I. (2021). Neuroimaging and neurodevelopmental outcome after early fetal growth restriction: NEUROPROJECT—FGR. *Pediatric Research*, *90*(4), 869–875. https://doi.org/10.1038/s41390-020-01333-1

Brouwer, M. J., Kersbergen, K. J., van Kooij, B. J. M., Benders, M. J. N. L., van Haastert, I. C., Koopman-Esseboom, C., Neil, J. J., de Vries, L. S., Kidokoro, H., Inder, T. E., & Groenendaal, F. (2017). Preterm brain injury on term-equivalent age MRI in relation to perinatal factors and neurodevelopmental outcome at two years. *PLoS ONE*, *12*(5). https://doi.org/10.1371/journal.pone.0177128

Burkitt, K., Kang, O., Jyoti, R., Mohamed, A. L., & Chaudhari, T. (2019). Comparison of cranial ultrasound and MRI for detecting BRAIN injury in extremely preterm infants and correlation with neurological outcomes at 1 and 3 years. *European Journal of Pediatrics*, *178*(7), 1053–1061. https://doi.org/10.1007/s00431-019-03388-7

Dewan, M. V., Herrmann, R., Schweiger, B., Sirin, S., Müller, H., Storbeck, T., Dransfeld, F., Felderhoff-Müser, U., & Hüning, B. (2019). Are Simple Magnetic Resonance Imaging Biomarkers Predictive of Neurodevelopmental Outcome at Two Years in Very Preterm Infants? *Neonatology*, *116*(4), 331–340. https://doi.org/10.1159/000501799

Goeral, K., Kasprian, G., Hüning, B. M., Waldhoer, T., Fuiko, R., Schmidbauer, V., Prayer, D., Felderhoff-Müser, U., Berger, A., Olischar, M., & Klebermass-Schrehof, K. (2022). A novel magnetic resonance imaging-based scoring system to predict outcome in neonates born preterm with intraventricular haemorrhage. *Developmental Medicine and Child Neurology*, *64*(5), 608–617. https://doi.org/10.1111/dmcn.15116

Haebich, K. M., Willmott, C., Scratch, S. E., Pascoe, L., Lee, K. J., Spencer-Smith, M. M., Cheong, J. L. Y., Inder, T. E., Doyle, L. W., Thompson, D. K., & Anderson, P. J. (2020). Neonatal brain abnormalities and brain volumes associated with goal setting outcomes in very preterm 13-year-olds. *Brain Imaging and Behavior*, *14*(4), 1062–1073. https://doi.org/10.1007/s11682-019-00039-1

Hammerl, M., Zagler, M., Zimmermann, M., Griesmaier, E., Janjic, T., Gizewski, E. R., Kiechl-Kohlendorfer, U., & Neubauer, V. (2020). Supratentorial Brain Metrics Predict Neurodevelopmental Outcome in Very Preterm Infants without Brain Injury at Age 2 Years. *Neonatology*, *117*(3), 287–293. https://doi.org/10.1159/000506836

Kostović Srzentić, M., Raguž, M., & Ozretić, D. (2020). Specific cognitive deficits in preschool age correlated with qualitative and quantitative MRI parameters in prematurely born children. *Pediatrics and Neonatology*, *61*(2), 160–167. https://doi.org/10.1016/j.pedneo.2019.09.003

Logan, J. W., Tan, J., Skalak, M., Fathi, O., He, L., Kline, J., Klebanoff, M., & Parikh, N. A. (2021). Adverse effects of perinatal illness severity on neurodevelopment are partially mediated by early brain abnormalities in infants born very preterm. *Journal of Perinatology*, *41*(3), 519–527. https://doi.org/10.1038/s41372-020-00854-1

Mayock, D. E., Gogcu, S., Puia-Dumitrescu, M., Shaw, D. W. W., Wright, J. N., Comstock, B. A., Heagerty, P. J., Juul, S. E., Wadhawan, R., Courtney, S. E., Robinson, T., Ahmad, K. A., Bendel-Stenzel, E., Baserga, M., LaGamma, E. F., Downey, L. C., Rao, R., Fahim, N., Lampland, A., … Widness, J. (2021). Association between Term Equivalent Brain Magnetic Resonance Imaging and 2-Year Outcomes in Extremely Preterm Infants: A Report from the Preterm Erythropoietin Neuroprotection Trial Cohort. *Journal of Pediatrics*, *239*, 117-125.e6. https://doi.org/10.1016/j.jpeds.2021.08.040

Mirmiran, M., Barnes, P. D., Keller, K., Constantinou, J. C., Fleisher, B. E., Hintz, S. R., & Ariagno, R. L. (2004). Neonatal brain magnetic resonance imaging before discharge is better than serial cranial ultrasound in predicting cerebral palsy in very low birth weight preterm infants. *Pediatrics*, *114*(4), 992–998. https://doi.org/10.1542/peds.2003-0772-L

Parikh, N. A., Harpster, K., He, L., Illapani, V. S. P., Khalid, F. C., Klebanoff, M. A., O'Shea, T. M., & Altaye, M. (2020). Novel diffuse white matter abnormality biomarker at term-equivalent age enhances prediction of long-term motor development in very preterm children. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-72632-0

Parikh, N. A., He, L., Priyanka Illapani, V. S., Altaye, M., Folger, A. T., & Yeates, K. O. (2020). Objectively Diagnosed Diffuse White Matter Abnormality at Term Is an Independent Predictor of Cognitive and Language Outcomes in Infants Born Very Preterm. *Journal of Pediatrics*, *220*, 56–63. https://doi.org/10.1016/j.jpeds.2020.01.034

Sheng, M., Guo, T., Mabbott, C., Chau, V., Synnes, A., de Vries, L. S., Grunau, R. E., & Miller, S. P. (2022). Ventricular Volume in Infants Born Very Preterm: Relationship with Brain Maturation and Neurodevelopment at Age 4.5 Years. *Journal of Pediatrics*, *248*, 51-58.e2. https://doi.org/10.1016/j.jpeds.2022.05.003

Skiöld, B., Eriksson, C., Eliasson, A. C., Ådén, U., & Vollmer, B. (2013). General movements and magnetic resonance imaging in the prediction of neuromotor outcome in children born extremely preterm. *Early Human Development*, *89*(7), 467–472. https://doi.org/10.1016/j.earlhumdev.2013.03.014

Skiöld, B., Hallberg, B., Vollmer, B., Ådén, U., Blennow, M., & Horsch, S. (2019). A Novel Scoring System for Term-Equivalent-Age Cranial Ultrasound in Extremely Preterm Infants. *Ultrasound in Medicine and Biology*, *45*(3), 786–794. https://doi.org/10.1016/j.ultrasmedbio.2018.11.005

Skiöld, B., Vollmer, B., Böhm, B., Hallberg, B., Horsch, S., Mosskin, M., Lagercrantz, H., Dén, U., & Blennow, M. (2012). Neonatal magnetic resonance imaging and outcome at age 30 months in extremely preterm infants. *Journal of Pediatrics*, *160*(4). https://doi.org/10.1016/j.jpeds.2011.09.053

Storbeck, T., Bruns, N., Weiss, C., Felderhoff-Müser, U., & Müller, H. (2020). Correlation of lateral ventricular size and deep gray matter volume in MRI at term equivalent age with neurodevelopmental outcome at a corrected age of 24 months and with handedness in preterm infants. *European Journal of Pediatrics*, *179*(2), 271–278. https://doi.org/10.1007/s00431-019-03496-4

Strahle, J. M., Triplett, R. L., Alexopoulos, D., Smyser, T. A., Rogers, C. E., Limbrick, D. D., & Smyser, C. D. (2019). Impaired hippocampal development and outcomes in very preterm infants with perinatal brain injury. *NeuroImage: Clinical*, *22*. https://doi.org/10.1016/j.nicl.2019.101787

van Gils, M. M., Dudink, J., Reiss, I. K. M., Swarte, R. M. C., van der Steen, J., Pel, J. J. M., & Kooiker, M. J. G. (2020). Brain Damage and Visuospatial Impairments: Exploring Early Structure-Function Associations in Children Born Very Preterm. *Pediatric Neurology*, *109*, 63–71. https://doi.org/10.1016/j.pediatrneurol.2019.12.010

Vesoulis, Z. A., Mathur, A. M., Ters, N. M. E., Herco, M., & Whitehead, H. v. (2018). A web-based calculator for the prediction of severe neurodevelopmental impairment in preterm infants using clinical and imaging characteristics. *Children*, *5*(11). https://doi.org/10.3390/children5110151

Woodward, L. J., Edgin, J. O., Thompson, D., & Inder, T. E. (2005). Object working memory deficits predicted by early brain injury and development in the preterm infant. *Brain*, *128*(11), 2578–2587. https://doi.org/10.1093/brain/awh618