Brain Topography (2021) 34:110–115
https://doi.org/10.1007/s10548-020-00807-z

CORRECTION

Correction to: Variation in Reported Human Head Tissue Electrical Conductivity Values

Hannah McCann[1,2] · Giampaolo Pisano[1] · Leandro Beltrachini[1,2]

Published online: 19 November 2020
© The Author(s) 2020

Correction to: Brain Topography (2019) 32:825–858
https://doi.org/10.1007/s10548-019-00710-2

The original publication of the article unfortunately contain mistakes. It has been corrected in this correction.

A GitHub Repository has been created to provide continual updates, since publication, for any measurements of human head electrical conductivity values (https://github.com/Head-Conductivity/Human-Head-Conductivity.git). This resource provides information on all values from the current literature, which will be updated as new data arises. We would appreciate any contribution of additional values and encourage authors to contact us if they become aware of further measurements.

Within the published manuscript, it has come to our attention that the inclusion of some research papers were erroneously described as utilising Magnetic Resonance Electrical Imaging Tomography (MREIT). These papers instead employed Magnetic Resonance Electrical Properties Tomography (MREPT) with frequencies above 1 kHz, greater than our included frequency range. These papers are thus to be excluded from the meta-analysis.

The original article can be found online at https://doi.org/10.1007/s10548-019-00710-2.

Communicated by Jens Haueisen.

✉ Hannah McCann
McCannHM@cardiff.ac.uk

Giampaolo Pisano
PisanoG@cardiff.ac.uk

Leandro Beltrachini
BeltrachiniL@cardiff.ac.uk

1 School of Physics and Astronomy, Cardiff University, Cardiff, UK

2 Cardiff University Brain Research Imaging Centre (CUBRIC), Cardiff, UK

Modifications are presented, in order, following this exclusion to various figures, tables and results.

Within the *Abstract*, 41, rather than 56 papers are now included in the data extraction. The recommended weighted average means for CSF, GM and WM should be altered to 1.736, 0.3787 and 0.1462 S/m respectively. Results for other tissues remain unchanged from the original publication.

Within the *3. Results* section, a total of 170 papers were excluded following full text assessment, resulting in a total of 41 studies (341 participants), utilising 4 methodologies; 14 for DAC, 11 for EIT, 8 for E/MEG, 9 for DTI. Of these included, 27 papers measured or estimated conductivity in vivo, 7 in vitro and 8 ex vivo, 28 reported on healthy participants, 10 on epilepsy and one on Parkinson's Disease, stroke and neurological disorders. The article no longer reports on tissues from the cerebellum or tumours.

The modified Tables 2 and 3, and Figures 2, 3, 9, 10, 11, 12 are shown below. Figure 8 is to be retracted from the published article due to insufficient data presented.

Within the *4. Discussion* section, the weighted average mean and standard deviation (in S/m) for CSF, GM and WM has been revised to: CSF = 1.736 ± 0.17, GM = 0.3787 ± 0.16, WM = 0.1462 ± 0.11. All mention and evaluation of papers utilising the excluded MREIT papers are omitted from the discussion section. These relate to the following references which are also to be excluded:

Haacke, E., Petropoulos, L., Nilges, E., & Wu, D. (1991). Extraction of conductivity and permittivity using magnetic resonance imaging. *Physics in Medicine & Biology, 36*(6), 723.

Voigt, T., Doessel, O., & Katscher, U. (2009). *Imaging conductivity and local SAR of the human brain*. Paper presented at the Proceedings of the 17th Annual Meeting of ISMRM, Honolulu, Hawaii, USA.

Voigt, T., Katscher, U., & Doessel, O. (2011). Quantitative Conductivity and Permittivity Imaging of the Human Brain Using Electric Properties Tomography.

Table 2 Summary of papers included in meta-analysis

Author	Method	Design	Frequency (Hz)	Participants	Age (years)	Pathology	Weight
Burger and van Milaan (1943)	DAC	Ex vivo	0	n = 1	Adult	Healthy	0.799
Rosenthal and Tobias (1948)	DAC	Ex vivo	1000	n = 1	Adult	Healthy	0.361
Burger and Van Dongen (1961)	DAC	Ex vivo	1000	n = 1	Adult	Healthy	0.444
Rush and Driscoll (1968)	DAC	Ex vivo		n = 1	Adult	Healthy	0.833
Cohen and Cuffin (1983b)	E/MEG	In vivo	0.3–300	n = 2 (m)	Adult	Healthy	0.705
Eriksen (1990)	E/MEG	In vivo	40	n = 4	Adult	Healthy	0.221
Law (1993)	DAC	In vitro	100	n = 1	Adult	Healthy	0.8723
Pierpaoli et al. (1996)	DTI	In vivo		n = 8	Adult	Healthy	0.344
Baumann et al. (1997)	DAC	In vitro	10–10 kHz	n = 7 (3m)	6.6	Neuro	0.69 ± 0.051
Sorensen et al. (1999)	DTI	In vivo		n = 1	Adult	Stroke	0.814
Uluğ and Van Zijl (1999)	DTI	In vivo		n = 5	Adult	Healthy	0.375
Oostendorp et al. (2000)	DAC	In vitro	10–100	n = 1, 2 (1m)	Adult	Healthy	0.768
Akhtari et al. (2000)	DAC	In vitro	20	n = 1	Adult	Healthy	0.855
Akhtari et al. (2002)	DAC	Ex vivo	10, 90	n = 4 (2m)	56 ± 26.7	Epilepsy	0.931
Hoekema et al. (2003)	DAC	In vitro, ex vivo	10	n = 1 (f), n = 5	68, 33.6 ± 15.9	Healthy	0.855
Gonçalves et al. (2003b)	EIT	In vivo	60	n = 6 (3m)	32.3 ± 7	Healthy	0.62
Gonçalves et al. (2003a)	EIT and E/MEG	In vivo	60	n = 6 (3m)	Adult	Healthy	0.496 ± 0.006
Baysal and Haueisen (2004)	E/MEG	In vivo	4	n = 10 (5m)	30 ± 13	Healthy	0.365 ± 0.368
Gutiérrez et al. (2004)	E/MEG	In vivo	2	n = 2 (1m)	32.5 ± 10.6	Healthy	0.52 ± 0.08
Clerc et al. (2005)	EIT	In vivo	110	n = 1	Adult	Healthy	0.639 ± 0.009
Sekino et al. (2005)	DTI	In vivo		n = 5	Adult	Healthy	0.672 ± 0.02
Lai et al. (2005)	EIT	In vivo	50	n = 5 (4m)	10 ± 2	Epilepsy	0.544
Zhang et al. (2006)	EIT	In vivo	50	n = 2	Paediatric	Epilepsy	0.656
Akhtari et al. (2006)	DAC	Ex vivo	5–1005	n = 21 (12m)	13.5 ± 15.1	Epilepsy	0.946
Tang et al. (2008)	DAC	In vitro	1 kHz	n = 48 (38m)	47.6	Healthy	0.999
Gattellaro et al. (2009)	DTI	In vivo		n = 20 (10m)	60.95 ± 11.9	Healthy, PD	0.344
Rullmann et al. (2009)	DTI	In vivo		n = 1	0.916	Epilepsy	0.975
Akhtari et al. (2010)	DAC	Ex vivo	6–1005	n = 15 (8m)	7.93 ± 6.04	Epilepsy	0.946
Gullmar et al. (2010)	DTI	In vivo		n = 1 (m)	30	Healthy	0.406
Wang et al. (2010)	DTI	In vivo		n = 71 (39m)	41.8 ± 14.5	Healthy	0.375
Dannhauer et al. (2011)	E/MEG	In vivo		n = 4	25 ± 4.6	Healthy	0.34
Aydin et al. (2014)	E/MEG	In vivo		n = 1 (f)	17	Epilepsy	0.86
Ouypornkochagorn et al. (2014)	EIT	In vivo		n = 1	Adult	Healthy	0.774 ± 0.01
Dabek et al. (2016)	EIT	In vivo	2	n = 9 (4m)	32.5 ± 10	Healthy	0.627 ± 0.037
Akhtari et al. (2016)	DAC	In vitro	10	n = 24	Paediatric	Epilepsy	0.698 ± 0.212
Acar et al. (2016)	E/MEG	In vivo		n = 2 (m)	21.5 ± 2.12	Healthy	0.718 ± 0.019
Koessler et al. (2017)	EIT	In vivo	50	n = 15 (10m)	38 ± 10	Epilepsy	0.643 ± 0.0478
Huang et al. (2017)	EIT	In vivo	1–100	n = 10	Adult	Epilepsy	0.613
Fernández-Corazza et al. (2017)	EIT	In vivo	27	n = 4 (m)	49 ± 4.8	Healthy	0.593 ± 0.078
Arumugam (2017)	EIT	In vivo	27	n = 10		Healthy	0.292
Chauhan et al. (2018)	DTI	In vivo	10	n = 2 (m)		Healthy	0.939

Method: direct applied current (DAC), electrical impedance tomography (EIT), electro- or magneto-encephalography (E/MEG), diffusion tensor imaging (DTI), Frequency (Hz, unless stated otherwise. Participants: number (n =), male/female (m/f). Age: mean ± standard deviation, unless stated otherwise. Pathology: neurological disorder (neuro), Parkinson's Disease (PD). Weight: mean ± standard deviation

Table 3 Descriptive statistics for each tissue type

Tissues	Minimum	Maximum	Mean	Weighted mean	Standard deviation	n. values	n. studies	n. participants
Scalp	0.137	2.1	0.5345	0.4137	0.1760	44	10	44
Muscle	0.1482	0.4167	0.3243	0.3243	0.1526	3	1	1
Whole skull	0.00182	1.718	0.0708	0.0160	0.019	99	20	121
Spongy	0.0012	0.2890	0.0559	0.0480	0.0735	16	4	10
Compact	0.0024	0.0079	0.0045	0.0046	0.0016	8	4	54
Outer compact	0.0008	0.0078	0.0047	0.0049	0.0029	10	2	5
Inner compact	0.0028	0.0129	0.0067	0.0068	0.0036	10	2	5
Sutures	0.0078	0.0735	0.0273	0.0266	0.0239	6	2	49
CSF	1.39	1.799	1.611	1.7358	0.1731	20	3	11
Whole brain	0.054	13.75	1.3519	0.3841	0.1017	44	6	30
GM	0.06	1.13	0.4083	0.3787	0.1549	46	11	140
WM	0.0646	0.6412	0.1455	0.1462	0.1054	71	8	71
WM_perp	0.0620	0.4390	0.1216	0.1175	0.0495	41	3	49
WM_par	0.0543	0.9150	0.1352	0.1226	0.0929	41	3	49
Blood	0.433	0.7622	0.5799	0.5737	0.106	14	3	3
EZ	0.2320	0.5278	0.2994	0.2949	0.0737	15	1	15
Dura			0.461			1	1	2
BSCR	11	290	58.69	50.4	38.93	51	10	47

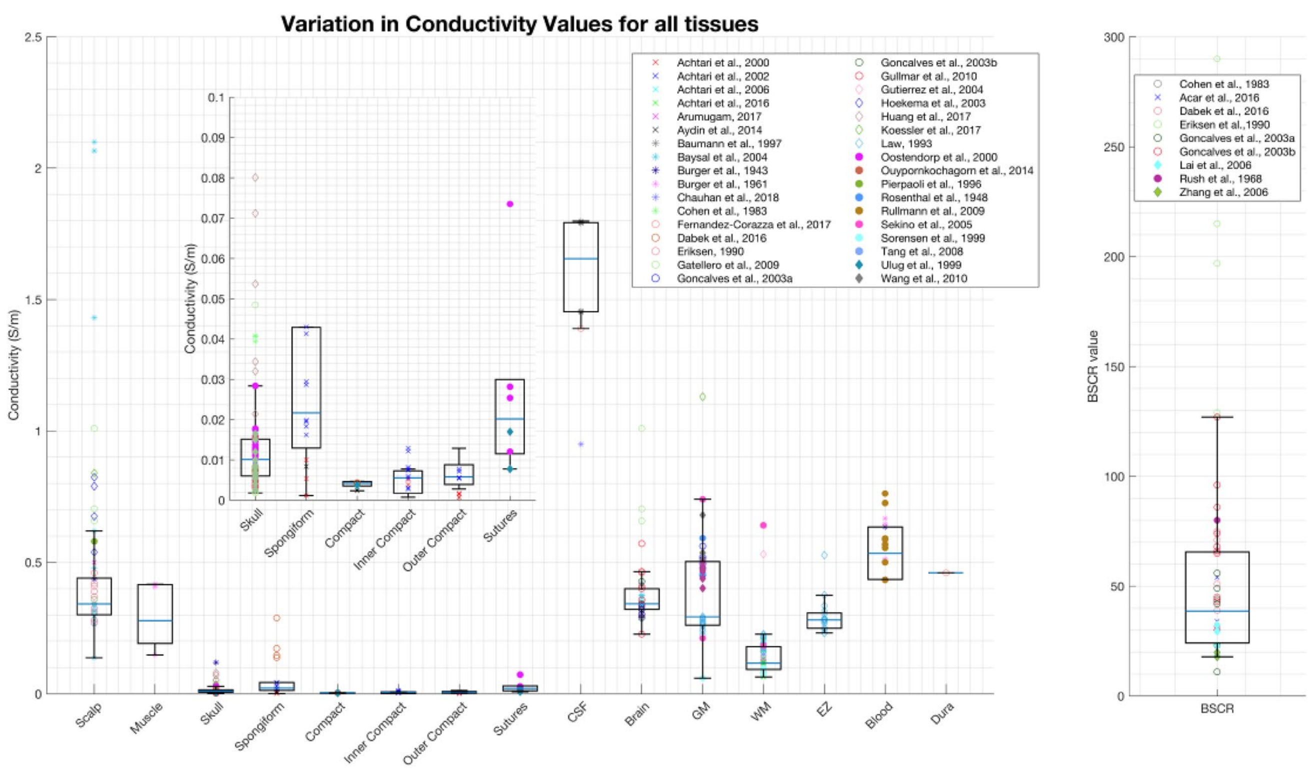


Figure 2

Magnetic Resonance in Medicine, 66(2), 456–466. https://doi.org/10.1002/mrm.22832

Van Lier, A., Hoogduin, J., Polders, D., Boer, V., Hendrikse, J., Robe, P.,... van den Berg, C. (2011). *Electrical conductivity imaging of brain tumours.* Paper presented at

Figure 3

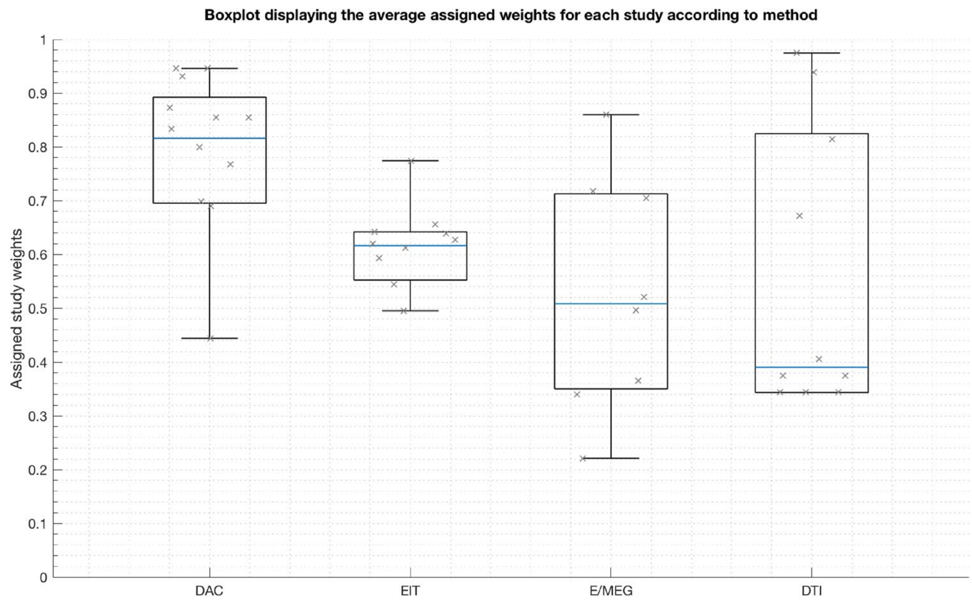
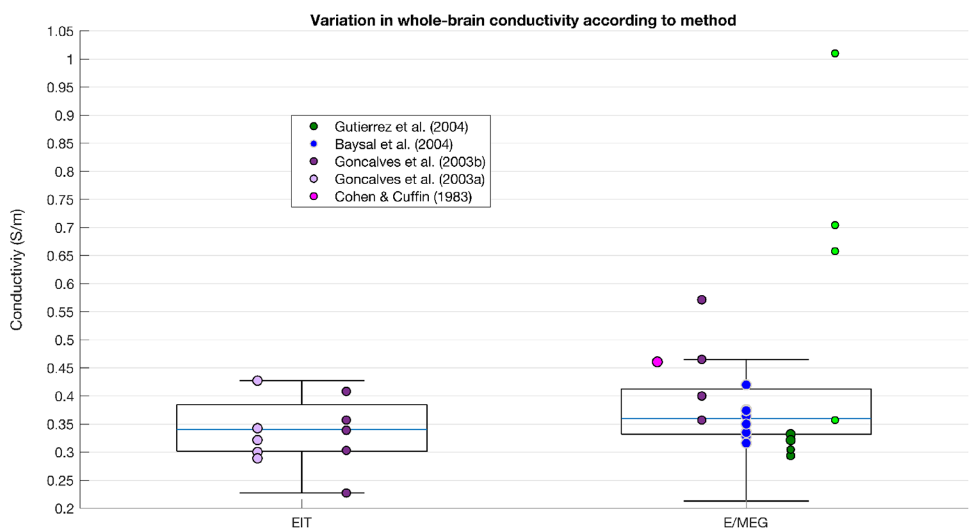


Figure 9



the Proceedings of the 19th Annual Meeting of ISMRM, Montreal, Canada.

van Lier, A., Kolk, A., Brundel, M., Hendriske, J., Luijten, J., Lagendijk, J., & van den Berg, C. (2012). *Electrical conductivity in ischemic stroke at 7.0 T: a case study.* Paper presented at the Proceedings of the 20th Scientific Meeting of the International Society of Magnetic Resonance in Medicine (ISMRM'12).

Huhndorf, M., Stehning, C., Rohr, A., Helle, M., Katscher, U., & Jansen, O. (2013). *Systematic brain tumor conductivity study with optimized EPT sequence and reconstruction algorithm.* Paper presented at the Proc. ISMRM.

Zhang, X., de Moortele, P. F. V., Schmitter, S., & He, B. (2013). Complex B1 mapping and electrical properties imaging of the human brain using a 16-channel transceiver coil at 7 T. *Magnetic resonance in medicine, 69*(5), 1285–1296.

Kim, D. H., Choi, N., Gho, S. M., Shin, J., & Liu, C. (2014). Simultaneous imaging of in vivo conductivity and susceptibility. *Magnetic resonance in medicine, 71*(3), 1144–1150.

Lee, J., Shin, J., & Kim, D. H. (2016). MR-based conductivity imaging using multiple receiver coils. *Magnetic resonance in medicine, 76*(2), 530–539.

Lee, S.-K., Bulumulla, S., Wiesinger, F., Sacolick, L., Sun, W., & Hancu, I. (2015). Tissue electrical property mapping from zero echo-time magnetic resonance imaging. *IEEE transactions on medical imaging, 34*(2), 541–550.

Figure 10

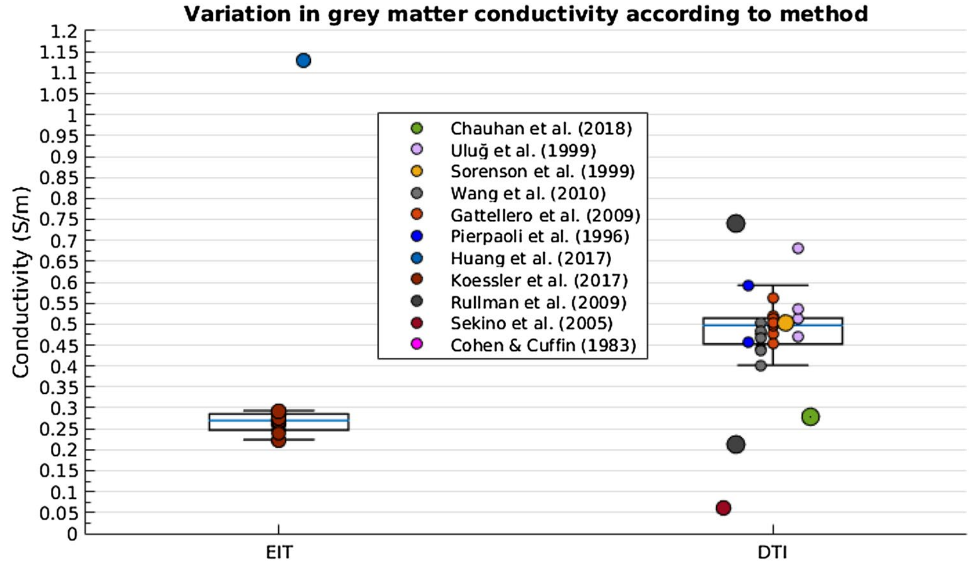
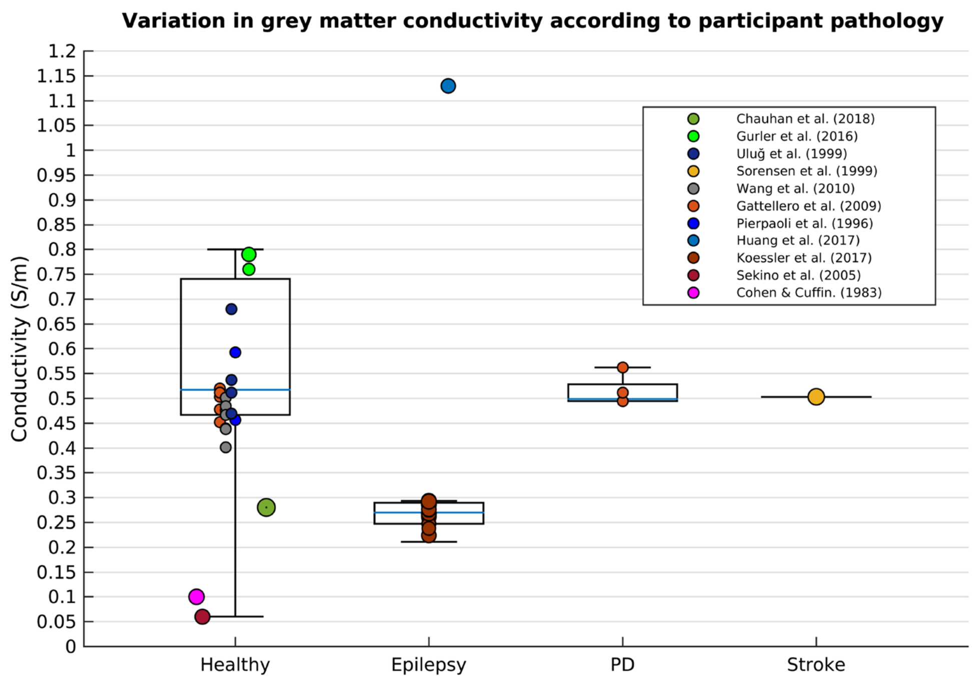


Figure 11



Gurler N., & Ider, Y.Z. (2017). Gradient-based electrical conductivity imagingusing MR phase. Magn Reson Med 77(1):137–150.

Ropella, K. M., & Noll, D. C. (2017) A regularized, model-based approach to phase-based conductivity mapping using MRI. *Magnetic resonance in medicine* (5), 2011–2021.

Hampe, N., Herrmann, M., Amthor, T., Findeklee, C., Doneva, M., & Katscher, U. (2018). Dictionary-based electric properties tomography. *Magnetic resonance in medicine*.

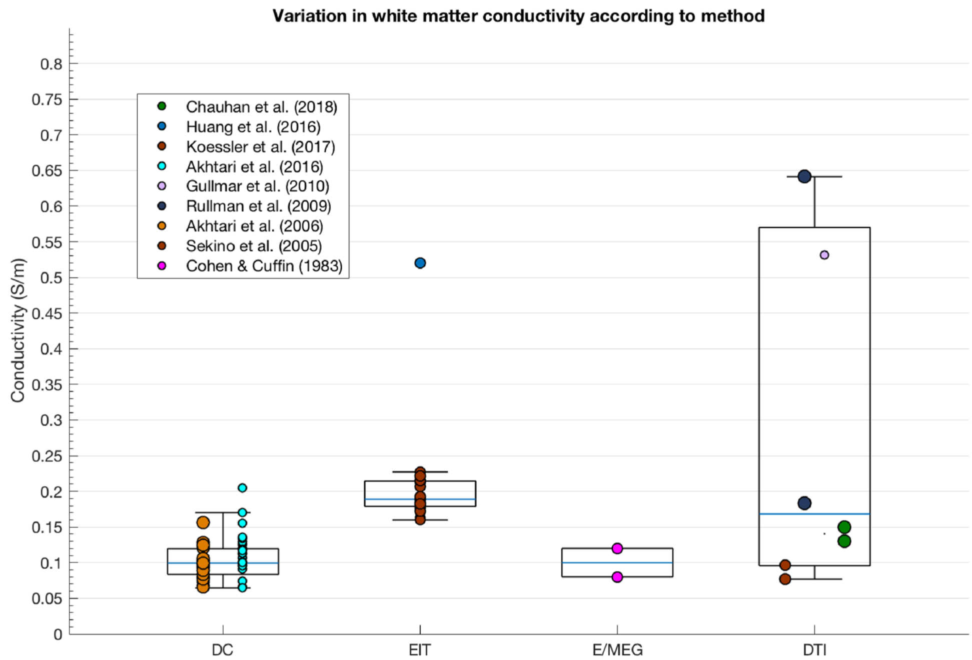
Michel, E., Hernandez, D., & Lee, S. Y. (2017). Electrical conductivity and permittivity maps of brain tissues derived from water content based on T1-weighted acquisition. *Magnetic resonance in medicine, 77*(3), 1094–1103.

Tha, K. K., Katscher, U., Yamaguchi, S., Stehning, C., Terasaka, S., Fujima, N.,... Van Cauteren, M. (2018). Noninvasive electrical conductivity measurement by MRI: a test of its validity and the electrical conductivity characteristics of glioma. *European radiology, 28*(1), 348–355.

Furthermore, after a thorough search of the published article the following errors are present in the references list:

Acar, Z. A., Ortiz-Mantilla, S., Benasich, A., & Makeig, S. (2016, Aug 16–20). *High-resolution EEG source imaging of one-year-old children.* Paper presented at the 38th

Figure 12



Annual International Conference of the IEEE-Engineering-in-Medicine-and-Biology-Society (EMBC), Orlando, FL.

Should read:

Acar ZA, Ortiz-Mantilla S, Benasich A, Makeig S (2016, August) High-resolution EEG source imaging of one-year-old children. In: Paper presented at the 38th annual international conference of the IEEE-Engineering-in-Medicine-and-Biology-Society (EMBC), Orlando, FL. IEEE, pp 117–120

Arumugam, E. T., Sergei. Price, Nick Rech, Dennis. Phan Luu, Phan. Tucker, Don. (2017). In-vivo Estimation of the Scalp and Skull Conductivity Using bEIT for Non-invasive Neuroimaging and Stimulation In: Brain Stimulation and Imaging Meeting.

Should read:

Essaki Arumugam EM, Turovets S, Price N, Rech D, Luu P, Tucker D (2017) In-vivo estimation of the scalp and skull conductivity using bEIT for non-invasive neuroimaging and stimulation. In: June 2017 conference: brain stimulation and imaging meeting, Vancouver, BC

Nurul AAL, Mahmood D, Mohd MK, Ibrahim S (2010) *A study of frequency effects on conductivity measurements.* RnD Seminar 2010: research and Development Seminar 2010, Malaysia.

Should read:

Latif NAiA, Dollah M, Kamaron MK, Ibrahim S (2010) A study of frequency effects on conductivity measurements. In: RnD Seminar 2010: research and development seminar 2010, Malaysia

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.