Graph theory

Prediction of seizure outcome following temporal lobectomy: A magnetoencephalography-based graph theory approach [1].

In mathematics graph theory is the study of graphs, which are mathematical structures used to model pairwise relations between objects. A graph in this context is made up of vertices, nodes, or points which are connected by edges, arcs, or lines. A graph may be undirected, meaning that there is no distinction between the two vertices associated with each edge, or its edges may be directed from one vertex to another; see Graph (discrete mathematics) for more detailed definitions and for other variations in the types of graph that are commonly considered. Graphs are one of the prime objects of study in discrete mathematics.

Graph theory is a promising mathematical tool to study the connectome. However, little research has been undertaken to correlate graph metrics to functional properties of the brain. In a study, Jones et al. reported a unique association between the strength of cortical regions and their function.

Eight structural graphs were constructed within DSI Studio using publicly available imaging data derived from the Human Connectome Project. Whole-brain fiber tractography was performed to quantify the strength of each cortical region comprising our atlas.

Rank-order analysis revealed 27 distinct areas with high average strength, several of which are associated with eloquent cortical functions. Area 4 localizes to the primary motor cortex and is important for fine motor control. Areas 2, 3a and 3b localize to the primary sensory cortex and are involved in primary sensory processing. Areas V1-V4 in the occipital pole are involved in primary visual processing. Several language areas, including area 44, were also found to have high average strength.

Regions of average high strength tend to localize to eloquent areas of the brain, such as the primary sensorimotor cortex, primary visual cortex, and Broca's area. Future studies will examine the dynamic effects of neurologic disease on this metric [2].

Resting state functional magnetic resonance imaging data were acquired using multi echo imaging, echo-planar imaging pre-operatively from five participants each with a right temporal-parietal-occipital glioblastoma. Complex networks analysis was initiated by parcellating the brain into anatomically regions amongst which connections were identified by retaining the most significant correlations between the respective wavelet decomposed time-series.

Key characteristics of complex networks described in healthy controls were preserved in these patients, including ubiquitous small world organization. An exponentially truncated power law fit to the degree distribution predicted findings of general network robustness to injury but with a core of hubs exhibiting disproportionate vulnerability. Tumours produced a consistent reduction in local and long-range connectivity with distinct patterns of connection loss depending on lesion location.

Connectome analysis is a feasible and novel approach to brain mapping in individual patients with brain tumours. Applications to pre-surgical planning include identifying regions critical to network function that should be preserved and visualising connections at risk from tumour resection. In the future one could use such data to model functional plasticity and recovery of cognitive deficits [3].

Unclassified

1: Jones RG, Briggs RG, Conner AK, Bonney PA, Fletcher LR, Ahsan SA, Chakraborty AR, Nix CE, Jacobs CC, Lack AM, Griffin DT, Teo C, Sughrue ME. Measuring graphical strength within the connectome: A neuroanatomic, parcellation-based study. J Neurol Sci. 2019 Nov 1;408:116529. doi: 10.1016/j.jns.2019.116529. [Epub ahead of print] PubMed PMID: 31710969.

2: Arbune AA, Popa I, Mindruta I, Beniczky S, Donos C, Daneasa A, Mălîia MD, Băjenaru OA, Ciurea J, Barborica A. Sleep modulates effective connectivity: A study using intracranial stimulation and recording. Clin Neurophysiol. 2019 Oct 24. pii: S1388-2457(19)31239-8. doi: 10.1016/j.clinph.2019.09.010. [Epub ahead of print] PubMed PMID: 31708382.

3: Luppi AI, Craig MM, Pappas I, Finoia P, Williams GB, Allanson J, Pickard JD, Owen AM, Naci L, Menon DK, Stamatakis EA. Consciousness-specific dynamic interactions of brain integration and functional diversity. Nat Commun. 2019 Oct 10;10(1):4616. doi: 10.1038/s41467-019-12658-9. PubMed PMID: 31601811; PubMed Central PMCID: PMC6787094.

4: Gonzalez-Escamilla G, Muthuraman M, Reich MM, Koirala N, Riedel C, Glaser M, Lange F, Deuschl G, Volkmann J, Groppa S. Cortical network fingerprints predict deep brain stimulation outcome in dystonia. Mov Disord. 2019 Aug 21. doi: 10.1002/mds.27808. [Epub ahead of print] PubMed PMID: 31433874.

5: Huang LC, Wu PA, Lin SZ, Pang CY, Chen SY. Graph theory and network topological metrics may be the potential biomarker in Parkinson's disease. J Clin Neurosci. 2019 Oct;68:235-242. doi: 10.1016/j.jocn.2019.07.082. Epub 2019 Aug 13. PubMed PMID: 31420273.

6: Li Q, Dong JW, Del Ferraro G, Petrovich Brennan N, Peck KK, Tabar V, Makse HA, Holodny AI. Functional Translocation of Broca's Area in a Low-Grade Left Frontal Glioma: Graph Theory Reveals the Novel, Adaptive Network Connectivity. Front Neurol. 2019 Jul 2;10:702. doi: 10.3389/fneur.2019.00702. eCollection 2019. PubMed PMID: 31333562; PubMed Central PMCID: PMC6615260.

7: Wykes RC, Khoo HM, Caciagli L, Blumenfeld H, Golshani P, Kapur J, Stern JM, Bernasconi A, Dedeurwaerdere S, Bernasconi N. WONOEP appraisal: Network concept from an imaging perspective. Epilepsia. 2019 Jul;60(7):1293-1305. doi: 10.1111/epi.16067. Epub 2019 Jun 9. PubMed PMID: 31179547; PubMed Central PMCID: PMC6667743.

8: Kandeepan S, Maudoux A, Ribeiro de Paula D, Zheng JY, Cabay JE, Gómez F, Chronik BA, Ridder D, Vanneste S, Soddu A. Tinnitus distress: a paradoxical attention to the sound? J Neurol. 2019 Sep;266(9):2197-2207. doi: 10.1007/s00415-019-09390-1. Epub 2019 May 31. PubMed PMID: 31152296.

9: Verwer JH, Reijmer YD, Koek HL, Biessels GJ; Utrecht Vascular Cognitive Impairment (VCI) Study Group. Physical Performance in Memory Clinic Patients: The Potential Role of the White Matter Network. J Am Geriatr Soc. 2019 Sep;67(9):1880-1887. doi: 10.1111/jgs.15987. Epub 2019 May 28. PubMed PMID: 31135061.

10: Hung SC, Lee CC, Chen HH, Chen C, Wu HM, Lin CP, Peng SJ. Early recovery of interhemispheric functional connectivity after corpus callosotomy. Epilepsia. 2019 Jun;60(6):1126-1136. doi: 10.1111/epi.14933. Epub 2019 May 14. PubMed PMID: 31087658.

11: Zhao C, Liang Y, Li C, Gao R, Wei J, Zuo R, Zhong Y, Ren Z, Geng X, Zhang G, Zhang X. Localization of Epileptogenic Zone Based on Cortico-Cortical Evoked Potential (CCEP): A Feature Extraction and Graph Theory Approach. Front Neuroinform. 2019 Apr 24;13:31. doi: 10.3389/fninf.2019.00031. eCollection 2019. PubMed PMID: 31068798; PubMed Central PMCID: PMC6491865.

12: Nagano-Saito A, Bellec P, Hanganu A, Jobert S, Mejia-Constain B, Degroot C, Lafontaine AL, Lissemore JI, Smart K, Benkelfat C, Monchi O. Why Is Aging a Risk Factor for Cognitive Impairment in Parkinson's Disease?-A Resting State fMRI Study. Front Neurol. 2019 Mar 22;10:267. doi: 10.3389/fneur.2019.00267. eCollection 2019. PubMed PMID: 30967835; PubMed Central PMCID: PMC6438889.

13: Chiosa V, Ciolac D, Groppa S, Koirala N, Pintea B, Vataman A, Winter Y, Gonzalez-Escamilla G, Muthuraman M, Groppa S. Large-scale network architecture and associated structural cortico-subcortical abnormalities in patients with sleep/awake-related seizures. Sleep. 2019 Apr 1;42(4). pii: zsz006. doi: 10.1093/sleep/zsz006. PubMed PMID: 30753617.

14: Lei Y, Song B, Chen L, Su J, Zhang X, Ni W, Yu Y, Xu B, Yu L, Gu Y, Mao Y. Reconfigured functional network dynamics in adult moyamoya disease: a resting-state fMRI study. Brain Imaging Behav. 2018 Dec 3. doi: 10.1007/s11682-018-0009-8. [Epub ahead of print] PubMed PMID: 30511114.

15: Jonak K, Krukow P, Jonak KE, Grochowski C, Karakuła-Juchnowicz H. Quantitative and Qualitative Comparison of EEG-Based Neural Network Organization in Two Schizophrenia Groups Differing in the Duration of Illness and Disease Burden: Graph Analysis With Application of the Minimum Spanning Tree. Clin EEG Neurosci. 2019 Jul;50(4):231-241. doi: 10.1177/1550059418807372. Epub 2018 Oct 16. PubMed PMID: 30322279.

16: Wang KL, Hu W, Liu TH, Zhao XB, Han CL, Xia XT, Zhang JG, Wang F, Meng FG. Metabolic covariance networks combining graph theory measuring aberrant topological patterns in mesial temporal lobe epilepsy. CNS Neurosci Ther. 2019 Mar;25(3):396-408. doi: 10.1111/cns.13073. Epub 2018 Oct 8. PubMed PMID: 30298594; PubMed Central PMCID: PMC6488969.

17: Hart MG, Romero-Garcia R, Price SJ, Suckling J. Global Effects of Focal Brain Tumors on Functional Complexity and Network Robustness: A Prospective Cohort Study. Neurosurgery. 2019 Jun 1;84(6):1201-1213. doi: 10.1093/neuros/nyy378. PubMed PMID: 30137556; PubMed Central PMCID: PMC6520100.

18: Ibrahim GM, Weil AG, Sedighim S, Schoen NB, Mikhail M, Sharma P, Guillen MR, Morgan BR, Wong S, Cajigas I, Jermakowicz WJ, Sandoval-Garcia C, Lewis EC, Fallah A, Altman N, Medina S, Pacheco-Jacome E, Jayakar P, Hyslop A, Miller I, Ragheb J, Bhatia S, Bernal B. Presurgical hyperconnectivity of the ablation volume is associated with seizure-freedom after magnetic resonance-guided laser interstitial thermal therapy. Seizure. 2018 Oct;61:89-93. doi: 10.1016/j.seizure.2018.08.006. Epub 2018 Aug 9. PubMed PMID: 30118930.

19: Chen S, Gallagher MJ, Hogg F, Papadopoulos MC, Saadoun S. Visibility Graph Analysis of Intraspinal Pressure Signal Predicts Functional Outcome in Spinal Cord Injured Patients. J Neurotrauma. 2018 Dec 15;35(24):2947-2956. doi: 10.1089/neu.2018.5775. Epub 2018 Sep 27. PubMed PMID: 30101641.

20: Li W, Zhang J, Zhou C, Hou W, Hu J, Feng H, Zheng X. Abnormal Functional Connectivity Density in Amyotrophic Lateral Sclerosis. Front Aging Neurosci. 2018 Jul 17;10:215. doi: 10.3389/fnagi.2018.00215. eCollection 2018. PubMed PMID: 30065647; PubMed Central PMCID:

PMC6056617.

21: Audrain S, Barnett AJ, McAndrews MP. Language network measures at rest indicate individual differences in naming decline after anterior temporal lobe resection. Hum Brain Mapp. 2018 Nov;39(11):4404-4419. doi: 10.1002/hbm.24281. Epub 2018 Jun 28. PubMed PMID: 29956405.

22: Aerts H, Schirner M, Jeurissen B, Van Roost D, Achten E, Ritter P, Marinazzo D. Modeling Brain Dynamics in Brain Tumor Patients Using the Virtual Brain. eNeuro. 2018 Jun 4;5(3). pii: ENEURO.0083-18.2018. doi: 10.1523/ENEURO.0083-18.2018. eCollection 2018 May-Jun. PubMed PMID: 29911173; PubMed Central PMCID: PMC6001263.

23: Taylor PN, Sinha N, Wang Y, Vos SB, de Tisi J, Miserocchi A, McEvoy AW, Winston GP, Duncan JS. The impact of epilepsy surgery on the structural connectome and its relation to outcome. Neuroimage Clin. 2018 Jan 31;18:202-214. doi: 10.1016/j.nicl.2018.01.028. eCollection 2018. PubMed PMID: 29876245; PubMed Central PMCID: PMC5987798.

24: Garcea FE, Chen Q, Vargas R, Narayan DA, Mahon BZ. Task- and domain-specific modulation of functional connectivity in the ventral and dorsal object-processing pathways. Brain Struct Funct. 2018 Jul;223(6):2589-2607. doi: 10.1007/s00429-018-1641-1. Epub 2018 Mar 13. PubMed PMID: 29536173; PubMed Central PMCID: PMC6252262.

25: Parker CS, Clayden JD, Cardoso MJ, Rodionov R, Duncan JS, Scott C, Diehl B, Ourselin S. Structural and effective connectivity in focal epilepsy. Neuroimage Clin. 2017 Dec 12;17:943-952. doi: 10.1016/j.nicl.2017.12.020. eCollection 2018. PubMed PMID: 29527498; PubMed Central PMCID: PMC5842760.

26: Zhang Y, Mao Z, Feng S, Liu X, Lan L, Zhang J, Yu X. Altered functional networks in long-term unilateral hearing loss: A connectome analysis. Brain Behav. 2018 Jan 18;8(2):e00912. doi: 10.1002/brb3.912. eCollection 2018 Feb. PubMed PMID: 29484269; PubMed Central PMCID: PMC5822584.

27: Dennis EL, Rashid F, Jahanshad N, Babikian T, Mink R, Babbitt C, Johnson J, Giza CC, Asarnow RF, Thompson PM. A NETWORK APPROACH TO EXAMINING INJURY SEVERITY IN PEDIATRIC TBI. Proc IEEE Int Symp Biomed Imaging. 2017;2017:105-108. doi: 10.1109/ISBI.2017.7950479. Epub 2017 Jun 19. PubMed PMID: 29201280; PubMed Central PMCID: PMC5706554.

28: Meyer-Bäse A, Roberts RG, Illan IA, Meyer-Bäse U, Lobbes M, Stadlbauer A, Pinker-Domenig K. Dynamical Graph Theory Networks Methods for the Analysis of Sparse Functional Connectivity Networks and for Determining Pinning Observability in Brain Networks. Front Comput Neurosci. 2017 Oct 5;11:87. doi: 10.3389/fncom.2017.00087. eCollection 2017. PubMed PMID: 29051730; PubMed Central PMCID: PMC5633615.

29: De Baene W, Rutten GJM, Sitskoorn MM. The Temporal Pattern of a Lesion Modulates the Functional Network Topology of Remote Brain Regions. Neural Plast. 2017;2017:3530723. doi: 10.1155/2017/3530723. Epub 2017 Aug 3. PubMed PMID: 28845308; PubMed Central PMCID: PMC5560088.

30: Wang MY, Wang J, Zhou J, Guan YG, Zhai F, Liu CQ, Xu FF, Han YX, Yan ZF, Luan GM. Identification of the epileptogenic zone of temporal lobe epilepsy from stereo-electroencephalography signals: A phase transfer entropy and graph theory approach. Neuroimage Clin. 2017 Jul 24;16:184-195. doi: 10.1016/j.nicl.2017.07.022. eCollection 2017. PubMed PMID: 28794979; PubMed Central PMCID: PMC5542420.

31: Chennu S, Annen J, Wannez S, Thibaut A, Chatelle C, Cassol H, Martens G, Schnakers C, Gosseries O, Menon D, Laureys S. Brain networks predict metabolism, diagnosis and prognosis at the bedside in disorders of consciousness. Brain. 2017 Aug 1;140(8):2120-2132. doi: 10.1093/brain/awx163. PubMed PMID: 28666351.

32: Kaushal M, Oni-Orisan A, Chen G, Li W, Leschke J, Ward D, Kalinosky B, Budde M, Schmit B, Li SJ, Muqeet V, Kurpad S. Large-Scale Network Analysis of Whole-Brain Resting-State Functional Connectivity in Spinal Cord Injury: A Comparative Study. Brain Connect. 2017 Sep;7(7):413-423. doi: 10.1089/brain.2016.0468. Epub 2017 Aug 30. PubMed PMID: 28657334.

33: Johnson EL, Dewar CD, Solbakk AK, Endestad T, Meling TR, Knight RT. Bidirectional Frontoparietal Oscillatory Systems Support Working Memory. Curr Biol. 2017 Jun 19;27(12):1829-1835.e4. doi: 10.1016/j.cub.2017.05.046. Epub 2017 Jun 9. PubMed PMID: 28602658; PubMed Central PMCID: PMC5546232.

34: Warren AEL, Harvey AS, Abbott DF, Vogrin SJ, Bailey C, Davidson A, Jackson GD, Archer JS. Cognitive network reorganization following surgical control of seizures in Lennox-Gastaut syndrome. Epilepsia. 2017 May;58(5):e75-e81. doi: 10.1111/epi.13720. Epub 2017 Mar 11. PubMed PMID: 28295228.

35: Kaushal M, Oni-Orisan A, Chen G, Li W, Leschke J, Ward BD, Kalinosky B, Budde MD, Schmit BD, Li SJ, Muqeet V, Kurpad SN. Evaluation of Whole-Brain Resting-State Functional Connectivity in Spinal Cord Injury: A Large-Scale Network Analysis Using Network-Based Statistic. J Neurotrauma. 2017 Mar 15;34(6):1278-1282. doi: 10.1089/neu.2016.4649. Epub 2017 Jan 27. PubMed PMID: 27937140.

36: Koshimori Y, Cho SS, Criaud M, Christopher L, Jacobs M, Ghadery C, Coakeley S, Harris M, Mizrahi R, Hamani C, Lang AE, Houle S, Strafella AP. Disrupted Nodal and Hub Organization Account for Brain Network Abnormalities in Parkinson's Disease. Front Aging Neurosci. 2016 Nov 10;8:259. eCollection 2016. PubMed PMID: 27891090; PubMed Central PMCID: PMC5102897.

37: Li YH, Ye XL, Liu QQ, Mao JW, Liang PJ, Xu JW, Zhang PM. Localization of epileptogenic zone based on graph analysis of stereo-EEG. Epilepsy Res. 2016 Dec;128:149-157. doi: 10.1016/j.eplepsyres.2016.10.021. Epub 2016 Nov 4. PubMed PMID: 27838502.

38: Mao JW, Ye XL, Li YH, Liang PJ, Xu JW, Zhang PM. Dynamic Network Connectivity Analysis to Identify Epileptogenic Zones Based on Stereo-Electroencephalography. Front Comput Neurosci. 2016 Oct 27;10:113. eCollection 2016. PubMed PMID: 27833545; PubMed Central PMCID: PMC5081385.

39: Yuan W, Meller A, Shimony JS, Nash T, Jones BV, Holland SK, Altaye M, Barnard H, Phillips J, Powell S, McKinstry RC, Limbrick DD, Rajagopal A, Mangano FT. Left hemisphere structural connectivity abnormality in pediatric hydrocephalus patients following surgery. Neuroimage Clin. 2016 Sep 4;12:631-639. eCollection 2016. PubMed PMID: 27722087; PubMed Central PMCID: PMC5048110.

40: Ibrahim GM, Morgan BR, Vogan VM, Leung RC, Anagnostou E, Taylor MJ. Mapping the Network of Neuropsychological Impairment in Children with Autism Spectrum Disorder: A Graph Theoretical Analysis. J Autism Dev Disord. 2016 Dec;46(12):3770-3777. PubMed PMID: 27696182.

41: Chang P, Li X, Ma C, Zhang S, Liu Z, Chen K, Ai L, Chang J, Zhang Z. The Effects of an APOE Promoter Polymorphism on Human White Matter Connectivity during Non-Demented Aging. J Alzheimers Dis. 2017;55(1):77-87. PubMed PMID: 27636845.

42: Kellermann TS, Bonilha L, Eskandari R, Garcia-Ramos C, Lin JJ, Hermann BP. Mapping the neuropsychological profile of temporal lobe epilepsy using cognitive network topology and graph

theory. Epilepsy Behav. 2016 Oct;63:9-16. doi: 10.1016/j.yebeh.2016.07.030. Epub 2016 Aug 15. PubMed PMID: 27532489; PubMed Central PMCID: PMC5048539.

43: Vecchio F, Miraglia F, Vollono C, Fuggetta F, Bramanti P, Cioni B, Rossini PM. Pre-seizure architecture of the local connections of the epileptic focus examined via graph-theory. Clin Neurophysiol. 2016 Oct;127(10):3252-8. doi: 10.1016/j.clinph.2016.07.006. Epub 2016 Aug 2. PubMed PMID: 27526391.

44: Mazzucchi E, Vollono C, Losurdo A, Testani E, Gnoni V, Di Blasi C, Giannantoni NM, Lapenta L, Brunetti V, Della Marca G. Hyperventilation in Patients With Focal Epilepsy: Electromagnetic Tomography, Functional Connectivity and Graph Theory - A Possible Tool in Epilepsy Diagnosis? J Clin Neurophysiol. 2017 Jan;34(1):92-99. doi: 10.1097/WNP.0000000000000329. PubMed PMID: 27490325.

46: De Vico Fallani F, Clausi S, Leggio M, Chavez M, Valencia M, Maglione AG, Babiloni F, Cincotti F, Mattia D, Molinari M. Interhemispheric Connectivity Characterizes Cortical Reorganization in Motor-Related Networks After Cerebellar Lesions. Cerebellum. 2017 Apr;16(2):358-375. doi: 10.1007/s12311-016-0811-z. PubMed PMID: 27372098.

47: Lee K, Lina JM, Gotman J, Grova C. SPARK: Sparsity-based analysis of reliable k-hubness and overlapping network structure in brain functional connectivity. Neuroimage. 2016 Jul 1;134:434-449. doi: 10.1016/j.neuroimage.2016.03.049. Epub 2016 Apr 2. PubMed PMID: 27046111.

48: Thompson DK, Chen J, Beare R, Adamson CL, Ellis R, Ahmadzai ZM, Kelly CE, Lee KJ, Zalesky A, Yang JYM, Hunt RW, Cheong JLY, Inder TE, Doyle LW, Seal ML, Anderson PJ. Structural connectivity relates to perinatal factors and functional impairment at 7years in children born very preterm. Neuroimage. 2016 Jul 1;134:328-337. doi: 10.1016/j.neuroimage.2016.03.070. Epub 2016 Apr 1. PubMed PMID: 27046108; PubMed Central PMCID: PMC4912891.

49: Mohan A, De Ridder D, Vanneste S. Graph theoretical analysis of brain connectivity in phantom sound perception. Sci Rep. 2016 Feb 2;6:19683. doi: 10.1038/srep19683. PubMed PMID: 26830446; PubMed Central PMCID: PMC4735645.

50: Harris NG, Verley DR, Gutman BA, Thompson PM, Yeh HJ, Brown JA. Disconnection and hyper-connectivity underlie reorganization after TBI: A rodent functional connectomic analysis. Exp Neurol. 2016 Mar;277:124-138. doi: 10.1016/j.expneurol.2015.12.020. Epub 2015 Dec 28. PubMed PMID: 26730520; PubMed Central PMCID: PMC4761291.

51: Beaty RE, Kaufman SB, Benedek M, Jung RE, Kenett YN, Jauk E, Neubauer AC, Silvia PJ. Personality and complex brain networks: The role of openness to experience in default network efficiency. Hum Brain Mapp. 2016 Feb;37(2):773-9. doi: 10.1002/hbm.23065. Epub 2015 Nov 26. PubMed PMID: 26610181; PubMed Central PMCID: PMC4738373.

52: Hart MG, Ypma RJ, Romero-Garcia R, Price SJ, Suckling J. Graph theory analysis of complex brain networks: new concepts in brain mapping applied to neurosurgery. J Neurosurg. 2016 Jun;124(6):1665-78. doi: 10.3171/2015.4.JNS142683. Epub 2015 Nov 6. Review. PubMed PMID: 26544769.

53: Borchardt V, Krause AL, Li M, van Tol MJ, Demenescu LR, Buchheim A, Metzger CD, Sweeney-Reed CM, Nolte T, Lord AR, Walter M. Dynamic disconnection of the supplementary motor area after processing of dismissive biographic narratives. Brain Behav. 2015 Sep 14;5(10):e00377. doi: 10.1002/brb3.377. eCollection 2015 Oct. PubMed PMID: 26516612; PubMed Central PMCID: PMC4614061.

54: Scheinost D, Kwon SH, Lacadie C, Vohr BR, Schneider KC, Papademetris X, Constable RT, Ment LR. Alterations in Anatomical Covariance in the Prematurely Born. Cereb Cortex. 2017 Jan 1;27(1):534-543. doi: 10.1093/cercor/bhv248. PubMed PMID: 26494796; PubMed Central PMCID: PMC5939217.

55: Yi LY, Liang X, Liu DM, Sun B, Ying S, Yang DB, Li QB, Jiang CL, Han Y. Disrupted topological organization of resting-state functional brain network in subcortical vascular mild cognitive impairment. CNS Neurosci Ther. 2015 Oct;21(10):846-54. doi: 10.1111/cns.12424. Epub 2015 Aug 8. PubMed PMID: 26257386; PubMed Central PMCID: PMC6493131.

56: Yuan W, Holland SK, Shimony JS, Altaye M, Mangano FT, Limbrick DD, Jones BV, Nash T, Rajagopal A, Simpson S, Ragan D, McKinstry RC. Abnormal structural connectivity in the brain networks of children with hydrocephalus. Neuroimage Clin. 2015 Apr 29;8:483-92. doi: 10.1016/j.nicl.2015.04.015. eCollection 2015. PubMed PMID: 26106573; PubMed Central PMCID: PMC4474092.

57: Garrison KA, Scheinost D, Finn ES, Shen X, Constable RT. The (in)stability of functional brain network measures across thresholds. Neuroimage. 2015 Sep;118:651-61. doi: 10.1016/j.neuroimage.2015.05.046. Epub 2015 May 27. PubMed PMID: 26021218; PubMed Central PMCID: PMC4554838.

58: Kocher M, Gleichgerrcht E, Nesland T, Rorden C, Fridriksson J, Spampinato MV, Bonilha L. Individual variability in the anatomical distribution of nodes participating in rich club structural networks. Front Neural Circuits. 2015 Apr 21;9:16. doi: 10.3389/fncir.2015.00016. eCollection 2015. PubMed PMID: 25954161; PubMed Central PMCID: PMC4405623.

59: Butler WE, Atai N, Carter B, Hochberg F. Informatic system for a global tissue-fluid biorepository with a graph theory-oriented graphical user interface. J Extracell Vesicles. 2014 Sep 22;3. doi: 10.3402/jev.v3.24247. eCollection 2014. PubMed PMID: 25317275; PubMed Central PMCID: PMC4172698.

60: Jeong W, Jin SH, Kim M, Kim JS, Chung CK. Abnormal functional brain network in epilepsy patients with focal cortical dysplasia. Epilepsy Res. 2014 Nov;108(9):1618-26. doi: 10.1016/j.eplepsyres.2014.09.006. Epub 2014 Sep 16. PubMed PMID: 25263846.

61: Keller CJ, Honey CJ, Mégevand P, Entz L, Ulbert I, Mehta AD. Mapping human brain networks with cortico-cortical evoked potentials. Philos Trans R Soc Lond B Biol Sci. 2014 Oct 5;369(1653). pii: 20130528. doi: 10.1098/rstb.2013.0528. PubMed PMID: 25180306; PubMed Central PMCID: PMC4150303.

62: Schmidt BT, Ghuman AS, Huppert TJ. Whole brain functional connectivity using phase locking measures of resting state magnetoencephalography. Front Neurosci. 2014 Jun 11;8:141. doi: 10.3389/fnins.2014.00141. eCollection 2014. PubMed PMID: 25018690; PubMed Central PMCID: PMC4071638.

63: Keller CJ, Honey CJ, Entz L, Bickel S, Groppe DM, Toth E, Ulbert I, Lado FA, Mehta AD. Corticocortical evoked potentials reveal projectors and integrators in human brain networks. J Neurosci. 2014 Jul 2;34(27):9152-63. doi: 10.1523/JNEUROSCI.4289-13.2014. PubMed PMID: 24990935; PubMed Central PMCID: PMC4078089.

64: Wang X, Fan Y, Zhao F, Wang Z, Ge J, Zhang K, Gao Z, Gao JH, Yang Y, Fan J, Zou Q, Liu P. Altered regional and circuit resting-state activity associated with unilateral hearing loss. PLoS One. 2014 May 1;9(5):e96126. doi: 10.1371/journal.pone.0096126. eCollection 2014. PubMed PMID: 24788317; PubMed Central PMCID: PMC4006821.

65: Ibrahim GM, Anderson R, Akiyama T, Ochi A, Otsubo H, Singh-Cadieux G, Donner E, Rutka JT, Snead OC 3rd, Doesburg SM. Neocortical pathological high-frequency oscillations are associated with frequency-dependent alterations in functional network topology. J Neurophysiol. 2013 Nov;110(10):2475-83. doi: 10.1152/jn.00034.2013. Epub 2013 Sep 4. PubMed PMID: 24004529.

66: Constable RT, Scheinost D, Finn ES, Shen X, Hampson M, Winstanley FS, Spencer DD, Papademetris X. Potential use and challenges of functional connectivity mapping in intractable epilepsy. Front Neurol. 2013 May 22;4:39. doi: 10.3389/fneur.2013.00039. eCollection 2013. PubMed PMID: 23734143; PubMed Central PMCID: PMC3660665.

67: Xu H, Ding S, Hu X, Yang K, Xiao C, Zou Y, Chen Y, Tao L, Liu H, Qian Z. Reduced efficiency of functional brain network underlying intellectual decline in patients with low-grade glioma. Neurosci Lett. 2013 May 24;543:27-31. doi: 10.1016/j.neulet.2013.02.062. Epub 2013 Apr 2. PubMed PMID: 23562503.

68: Bernhardt BC, Chen Z, He Y, Evans AC, Bernasconi N. Graph-theoretical analysis reveals disrupted small-world organization of cortical thickness correlation networks in temporal lobe epilepsy. Cereb Cortex. 2011 Sep;21(9):2147-57. doi: 10.1093/cercor/bhq291. Epub 2011 Feb 17. PubMed PMID: 21330467.

69: Douw L, van Dellen E, Baayen JC, Klein M, Velis DN, Alpherts WC, Heimans JJ, Reijneveld JC, Stam CJ. The lesioned brain: still a small-world? Front Hum Neurosci. 2010 Nov 11;4:174. doi: 10.3389/fnhum.2010.00174. eCollection 2010. PubMed PMID: 21120140; PubMed Central PMCID: PMC2991225.

70: Zamorano L, Jiang Z, Kadi AM. Computer-assisted neurosurgery system: Wayne State University hardware and software configuration. Comput Med Imaging Graph. 1994 Jul-Aug;18(4):257-71. PubMed PMID: 7923045.

1)
Mukherjee J, Kenchaiah R, Gautham BK, Narayanan C, Afsar M, Narayanan M, Rajeswaran J, Asranna A, Mundlamuri RC, Viswanathan LG, Mahadevan A, Sadashiva N, Arivazhagan A, Karthik K, Bharath RD, Saini J, Kandavel T, Rao MB, Sinha S. Prediction of seizure outcome following temporal lobectomy: A magnetoencephalography-based graph theory approach“. Seizure. 2022 Mar 18;97:73-81. doi: 10.1016/j.seizure.2022.03.012. Epub ahead of print. PMID: 35344920.

2)
Jones RG, Briggs RG, Conner AK, Bonney PA, Fletcher LR, Ahsan SA, Chakraborty AR, Nix CE, Jacobs CC, Lack AM, Griffin DT, Teo C, Sughrue ME. Measuring graphical strength within the connectome: A neuroanatomic, parcellation-based study. J Neurol Sci. 2019 Nov 1;408:116529. doi: 10.1016/j.jns.2019.116529. [Epub ahead of print] PubMed PMID: 31710969.

3)
Hart MG, Price SJ, Suckling J. Connectome analysis for pre-operative brain mapping in neurosurgery. Br J Neurosurg. 2016 Jul 22:1-12. [Epub ahead of print] PubMed PMID: 27447756.