Electrical impedance tomography

The purpose of this study is to explore whether electrical impedance tomography (EIT)-guided individualized positive end-expiratory pressure (PEEP) can reduce the incidence of pulmonary complications within 1 week following a craniotomy compared with a single PEEP (PEEP = 6 cmH2O) from dura suturing to extubation.

Methods: A randomized controlled trial will be conducted at the Second Affiliated Hospital of Soochou University. Five hundred forty patients undergoing a craniotomy in the supine position will be randomly allocated into the P6 (PEEP = 6 cmH2O) or Pi (individualized PEEP) group. Both groups of patients will receive a lung recruitment maneuver before suturing the dura. Then, the P6 group will receive 6 cmH2O PEEP, and the Pi group will receive EIT-guided individualized PEEP. The incidence and severity score of pulmonary complications within 1 week following surgery, the lung ultrasound score (LUS), regional cerebral oxygen saturation (rScO2), and PaO2/FiO2 before anesthesia (T0), 10 min after extubation (T1), 24 h after extubation (T2), and 72 h after extubation (T3) will be compared between the two groups. The duration of surgery and anesthesia, the level and duration of PEEP during surgery, the volume of liquid intake and output during surgery, and the postoperative ICU and hospital stays will be recorded. The main outcome of this study will be the incidence of pulmonary complications within 1 week after surgery.

Discussion: The purposes of this study are to determine whether EIT-guided individualized PEEP from the beginning of dura suturing to extubation reduces the incidence of pulmonary complications within 1 week after a craniotomy compared with a single constant PEEP and to evaluate the length of ICU and hospital stays. If our results are positive, this study will show that EIT-guided individualized PEEP is better than a single constant PEEP and can further improve the prognosis of neurosurgical patients and reduce hospitalization costs, which will promote the wide application of individualized PEEP in clinical anesthesia.

Trial registration: Chinese Clinical Trial Registry CHiCTR2100051200. Registered on 15 September 2021 [1)].

2: Klassen BT, Rotter J, Crane C, Kaufmann TJ, Miller KJ. Elevated Electrode Impedances During Deep Brain Stimulation Surgery May Be Due to Peri-Electrode Air Collections. Cureus. 2022 Jan 23;14(1):e21518. doi: 10.7759/cureus.21518. PMID: 35223294; PMCID: PMC8862689.

3: Regenhardt RW, González RG, He J, Lev MH, Singhal AB. Symmetric CTA Collaterals Identify Patients with Slow-progressing Stroke Likely to Benefit from Late Thrombectomy. Radiology. 2022 Feb;302(2):400-407. doi: 10.1148/radiol.2021210455. Epub 2021 Nov 2. PMID: 34726532; PMCID: PMC8792270.

4: Witkowska-Wrobel A, Aristovich K, Crawford A, Perkins JD, Holder D. Imaging of focal seizures with Electrical Impedance Tomography and depth electrodes in real time. Neuroimage. 2021 Jul 1;234:117972. doi: 10.1016/j.neuroimage.2021.117972. Epub 2021 Mar 20. PMID: 33757909; PMCID: PMC8204270.

5: Morais CC, Campos SL, Lima CS, Monte LJ, Bandeira MCP, Brandão DC, Costa EL, Aliverti A, Amato MB, Andrade AD. Acute Effects of Lung Expansion Maneuvers in Comatose Subjects With Prolonged Bed Rest. Respir Care. 2021 Feb;66(2):240-247. doi: 10.4187/respcare.07535. Epub 2020 Oct 6. PMID:

33024002.

6: Kim JP, Lee W, Suh J, Lee H, Lee K, Ahn HY, Seo MJ, Ryu ST, Aristovich K, Holder D, Kim SJ. A 10 nV/rt Hz noise level 32-channel neural impedance sensing ASIC for local activation imaging on nerve section. Annu Int Conf IEEE Eng Med Biol Soc. 2020 Jul;2020:4012-4015. doi: 10.1109/EMBC44109.2020.9176708. PMID: 33018879.

7: Tas J, van Gassel RJJ, Heines SJH, Mulder MMG, Heijnen NFL, Acampo-de Jong MJ, Bels JLM, Bennis FC, Koelmann M, Groven RVM, Donkers MA, van Rosmalen F, Hermans BJM, Meex SJ, Mingels A, Bekers O, Savelkoul P, Oude Lashof AML, Wildberger J, Tijssen FH, Buhre W, Sels JEM, Ghossein-Doha C, Driessen RGH, Kubben PL, Janssen MLF, Nicolaes GAF, Strauch U, Geyik Z, Delnoij TSR, Walraven KHM, Stehouwer CD, Verbunt JAMCF, Van Mook WNKA, van Santen S, Schnabel RM, Aries MJH, van de Poll MCG, Bergmans D, van der Horst ICC, van Kuijk S, van Bussel BCT. Serial measurements in COVID-19-induced acute respiratory disease to unravel heterogeneity of the disease course: design of the Maastricht Intensive Care COVID cohort (MaastrICCht). BMJ Open. 2020 Sep 29;10(9):e040175. doi: 10.1136/bmjopen-2020-040175. PMID: 32994259; PMCID: PMC7526030.

8: Vassal F, Dilly D, Boutet C, Bertholon F, Charier D, Pommier B. White matter tracts involved by deep brain stimulation of the subthalamic nucleus in Parkinson's disease: a connectivity study based on preoperative diffusion tensor imaging tractography. Br J Neurosurg. 2020 Apr;34(2):187-195. doi: 10.1080/02688697.2019.1701630. Epub 2019 Dec 13. PMID: 31833430.

9: Oribe S, Yoshida S, Kusama S, Osawa SI, Nakagawa A, Iwasaki M, Tominaga T, Nishizawa M. Hydrogel-Based Organic Subdural Electrode with High Conformability to Brain Surface. Sci Rep. 2019 Sep 16;9(1):13379. doi: 10.1038/s41598-019-49772-z. PMID: 31527626; PMCID: PMC6746719.

10: Yang B, Li B, Xu C, Hu S, Dai M, Xia J, Luo P, Shi X, Zhao Z, Dong X, Fei Z, Fu F. Comparison of electrical impedance tomography and intracranial pressure during dehydration treatment of cerebral edema. Neuroimage Clin. 2019;23:101909. doi: 10.1016/j.nicl.2019.101909. Epub 2019 Jun 26. PMID: 31284231; PMCID: PMC6612924.

11: Boutet A, Hancu I, Saha U, Crawley A, Xu DS, Ranjan M, Hlasny E, Chen R, Foltz W, Sammartino F, Coblentz A, Kucharczyk W, Lozano AM. 3-Tesla MRI of deep brain stimulation patients: safety assessment of coils and pulse sequences. J Neurosurg. 2019 Feb 22;132(2):586-594. doi: 10.3171/2018.11.JNS181338. PMID: 30797197.

12: Lin MH, Chung CY, Chen KT, Yeh JC, Lee TH, Lee MH, Lee IN, Huang WC, Yang JT. Comparison between Polybutylcyanoacrylate Nanoparticles with Either Surface- Adsorbed or Encapsulated Brain-Derived Neurotrophic Factor on the Neural Differentiation of iPSCs. Int J Mol Sci. 2019 Jan 6;20(1):182. doi: 10.3390/ijms20010182. PMID: 30621332; PMCID: PMC6337453.

13: Moteki H, Fujinaga Y, Goto T, Usami SI. Pneumolabyrinth, intracochlear and vestibular fluid loss after cochlear implantation. Auris Nasus Larynx. 2018 Oct;45(5):1116-1120. doi: 10.1016/j.anl.2018.03.004. Epub 2018 Apr 19. PMID: 29680680.

14: Blecharz-Lang KG, Wagner J, Fries A, Nieminen-Kelhä M, Rösner J, Schneider UC, Vajkoczy P. Interleukin 6-Mediated Endothelial Barrier Disturbances Can Be Attenuated by Blockade of the IL6 Receptor Expressed in Brain Microvascular Endothelial Cells. Transl Stroke Res. 2018 Dec;9(6):631-642. doi: 10.1007/s12975-018-0614-2. Epub 2018 Feb 10. PMID: 29429002.

15: Wang L, Sun Y, Xu X, Dong X, Gao F. Real-time imaging of epileptic seizures in rats using electrical impedance tomography. Neuroreport. 2017 Aug 2;28(11):689-693. doi:

10.1097/WNR.0000000000000823. PMID: 28628556; PMCID: PMC5491225.

16: Yang L, Liu W, Chen R, Zhang G, Li W, Fu F, Dong X. In Vivo Bioimpedance Spectroscopy Characterization of Healthy, Hemorrhagic and Ischemic Rabbit Brain within 10 Hz-1 MHz. Sensors (Basel). 2017 Apr 7;17(4):791. doi: 10.3390/s17040791. PMID: 28387710; PMCID: PMC5422064.

17: Aristovich KY, Packham BC, Koo H, Santos GSD, McEvoy A, Holder DS. Imaging fast electrical activity in the brain with electrical impedance tomography. Neuroimage. 2016 Jan 1;124(Pt A):204-213. doi: 10.1016/j.neuroimage.2015.08.071. Epub 2015 Sep 5. PMID: 26348559; PMCID: PMC4655915.

18: Duffy BA, Choy M, Chuapoco MR, Madsen M, Lee JH. MRI compatible optrodes for simultaneous LFP and optogenetic fMRI investigation of seizure-like afterdischarges. Neuroimage. 2015 Dec;123:173-84. doi: 10.1016/j.neuroimage.2015.07.038. Epub 2015 Jul 21. PMID: 26208873; PMCID: PMC5573166.

19: Awara K, Kitai R, Isozaki M, Neishi H, Kikuta K, Fushisato N, Kawamoto A. Thin-film electroencephalographic electrodes using multi-walled carbon nanotubes are effective for neurosurgery. Biomed Eng Online. 2014 Dec 15;13:166. doi: 10.1186/1475-925X-13-166. PMID: 25511926; PMCID: PMC4290091.

20: Fukushima M, Saunders RC, Mullarkey M, Doyle AM, Mishkin M, Fujii N. An electrocorticographic electrode array for simultaneous recording from medial, lateral, and intrasulcal surface of the cortex in macaque monkeys. J Neurosci Methods. 2014 Aug 15;233:155-65. doi: 10.1016/j.jneumeth.2014.06.022. Epub 2014 Jun 24. Erratum in: J Neurosci Methods. 2015 Apr 30;245:205-6. PMID: 24972186; PMCID: PMC4123547.

21: Satzer D, Maurer EW, Lanctin D, Guan W, Abosch A. Anatomic correlates of deep brain stimulation electrode impedance. J Neurol Neurosurg Psychiatry. 2015 Apr;86(4):398-403. doi: 10.1136/jnnp-2013-307284. Epub 2014 Jun 16. PMID: 24935985.

22: Manwaring PK, Moodie KL, Hartov A, Manwaring KH, Halter RJ. Intracranial electrical impedance tomography: a method of continuous monitoring in an animal model of head trauma. Anesth Analg. 2013 Oct;117(4):866-875. doi: 10.1213/ANE.0b013e318290c7b7. Epub 2013 Jul 10. PMID: 23842194; PMCID: PMC3783592.

23: Avdievich NI, Pan JW, Hetherington HP. Resonant inductive decoupling (RID) for transceiver arrays to compensate for both reactive and resistive components of the mutual impedance. NMR Biomed. 2013 Nov;26(11):1547-54. doi: 10.1002/nbm.2989. Epub 2013 Jun 18. PMID: 23775840; PMCID: PMC3800502.

24: Dai M, Li B, Hu S, Xu C, Yang B, Li J, Fu F, Fei Z, Dong X. In vivo imaging of twist drill drainage for subdural hematoma: a clinical feasibility study on electrical impedance tomography for measuring intracranial bleeding in humans. PLoS One. 2013;8(1):e55020. doi: 10.1371/journal.pone.0055020. Epub 2013 Jan 25. PMID: 23372808; PMCID: PMC3555836.

25: Donohue ML, Swaminathan V, Gilbert JL, Fox CW, Smale J, Moquin RR, Calancie B. Intraoperative neuromonitoring: can the results of direct stimulation of titanium-alloy pedicle screws in the thoracic spine be trusted? J Clin Neurophysiol. 2012 Dec;29(6):502-8. doi: 10.1097/WNP.0b013e3182767aac. PMID: 23207589.

26: Arpinar VE, Hamamura MJ, Degirmenci E, Muftuler LT. MREIT experiments with 200 μA injected currents: a feasibility study using two reconstruction algorithms, SMM and harmonic B(Z). Phys Med Biol. 2012 Jul 7;57(13):4245-61. doi: 10.1088/0031-9155/57/13/4245. Epub 2012 Jun 8. PMID:

22684125; PMCID: PMC3381422.

27: Ray A, Chan LL, Gonzalez A, Humayun MS, Weiland JD. Impedance as a method to sense proximity at the electrode-retina interface. IEEE Trans Neural Syst Rehabil Eng. 2011 Dec;19(6):696-9. doi: 10.1109/TNSRE.2011.2169428. Epub 2011 Oct 6. PMID: 21984523.

28: Dai M, Wang L, Xu C, Li L, Gao G, Dong X. Real-time imaging of subarachnoid hemorrhage in piglets with electrical impedance tomography. Physiol Meas. 2010 Sep;31(9):1229-39. doi: 10.1088/0967-3334/31/9/012. Epub 2010 Jul 28. PMID: 20664164.

29: Marceglia S, Mrakic-Sposta S, Tommasi G, Bartolomei L, Foresti C, Valzania F, Galati S, Stefani A, Tamma F, Priori A; DBS Study Group of The Italian Neurological Society. Multicenter study report: electrophysiological monitoring procedures for subthalamic deep brain stimulation surgery in Parkinson's disease. Neurol Sci. 2010 Aug;31(4):449-57. doi: 10.1007/s10072-010-0254-0. Epub 2010 Apr 23. PMID: 20414706.

30: Johansson JD, Blomstedt P, Haj-Hosseini N, Bergenheim AT, Eriksson O, Wårdell K. Combined diffuse light reflectance and electrical impedance measurements as a navigation aid in deep brain surgery. Stereotact Funct Neurosurg. 2009;87(2):105-13. doi: 10.1159/000202977. Epub 2009 Feb 18. PMID: 19223697.

31: Holdefer RN, Sadleir R, Russell MJ. Predicted current densities in the brain during transcranial electrical stimulation. Clin Neurophysiol. 2006 Jun;117(6):1388-97. doi: 10.1016/j.clinph.2006.02.020. Epub 2006 Apr 27. PMID: 16644273; PMCID: PMC2426751.

32: Fabrizi L, Sparkes M, Horesh L, Perez-Juste Abascal JF, McEwan A, Bayford RH, Elwes R, Binnie CD, Holder DS. Factors limiting the application of electrical impedance tomography for identification of regional conductivity changes using scalp electrodes during epileptic seizures in humans. Physiol Meas. 2006 May;27(5):S163-74. doi: 10.1088/0967-3334/27/5/S14. Epub 2006 Apr 20. PMID: 16636408.

33: Raslan AM. Percutaneous computed tomography-guided transdiscal low cervical cordotomy for cancer pain as a method to avoid sleep apnea. Stereotact Funct Neurosurg. 2005;83(4):159-64. doi: 10.1159/000088992. Epub 2005 Oct 17. PMID: 16230863.

34: Gasser T, Sandalcioglu E, Schoch B, Gizewski E, Forsting M, Stolke D, Wiedemayer H. Functional magnetic resonance imaging in anesthetized patients: a relevant step toward real-time intraoperative functional neuroimaging. Neurosurgery. 2005 Jul;57(1 Suppl):94-9; discussion 94-9. doi: 10.1227/01.neu.0000163488.91335.c5. PMID: 15987574.

35: Uitti RJ, Tsuboi Y, Pooley RA, Putzke JD, Turk MF, Wszolek ZK, Witte RJ, Wharen RE Jr. Magnetic resonance imaging and deep brain stimulation. Neurosurgery. 2002 Dec;51(6):1423-28; discussion 1428-31. PMID: 12445347.

36: Aziz TZ, Nandi D, Parkin S, Liu X, Giladi N, Bain P, Gregory RG, Joint C, Scott RB, Stein JF. Targeting the subthalamic nucleus. Stereotact Funct Neurosurg. 2001;77(1-4):87-90. doi: 10.1159/000064602. PMID: 12378062.

37: Siemionow V, Yue GH, Barnett GH, Sahgal V, Heilbrun MP. Measurement of tissue electrical impedance confirms stereotactically localized internal segment of the globus pallidus during surgery. J Neurosci Methods. 2000 Mar 15;96(2):113-7. doi: 10.1016/s0165-0270(99)00188-0. PMID: 10720675.

38: Carlson JD, Iacono RP. Electrophysiological versus image-based targeting in the posteroventral pallidotomy. Comput Aided Surg. 1999;4(2):93-100. doi: 10.1002/(SICI)1097-0150(1999)4:2<93::AID-IGS4>3.0.CO;2-S. PMID: 10494139.

39: Heilbrun MP, Koehler S, McDonald P, Faour F. Optimal target localization for ventroposterolateral pallidotomy: the role of imaging, impedance measurement, macrostimulation and microelectrode recording. Stereotact Funct Neurosurg. 1997;69(1-4 Pt 2):19-27. doi: 10.1159/000099850. PMID: 9711731.

40: Zileli M, Coşkun E, Yegül I, Uyar M. Electrophysiological monitoring during CT-guided percutaneous cordotomy. Acta Neurochir Suppl. 1995;64:92-6. doi: 10.1007/978-3-7091-9419-5_20. PMID: 8748592.

41: Hobza V, Jakubec J, Německová J, Němecek S, Sercl M. Impedance monitoring in the stereotactic localization of intracranial structures. Sb Ved Pr Lek Fak Karlovy Univerzity Hradci Kralove. 1995;38(1):33-46. PMID: 7569726.

42: Boone K, Lewis AM, Holder DS. Imaging of cortical spreading depression by EIT: implications for localization of epileptic foci. Physiol Meas. 1994 May;15 Suppl 2a:A189-98. doi: 10.1088/0967-3334/15/2a/024. PMID: 8087042.

43: Verheul HB, Balázs R, Berkelbach van der Sprenkel JW, Tulleken CA, Nicolay K, Tamminga KS, van Lookeren Campagne M. Comparison of diffusion-weighted MRI with changes in cell volume in a rat model of brain injury. NMR Biomed. 1994 Mar;7(1-2):96-100. doi: 10.1002/nbm.1940070115. Erratum in: NMR Biomed 1994 Dec;7(8):374. PMID: 8068532.

44: Rajshekhar V. Continuous impedance monitoring during CT-guided stereotactic surgery: relative value in cystic and solid lesions. Br J Neurosurg. 1992;6(5):439-44. doi: 10.3109/02688699208995033. PMID: 1333228.

45: Gorecki J, Dolan EJ, Tasker RR, Kucharczyk W. Correlation of CT and MR with impedance monitoring and histopathology in stereotactic biopsies. Can J Neurol Sci. 1990 May;17(2):184-9. doi: 10.1017/s0317167100030420. PMID: 2192789.

46: Holder DS, Gardner-Medwin AR. Some possible neurological applications of applied potential tomography. Clin Phys Physiol Meas. 1988;9 Suppl A:111-9. doi: 10.1088/0143-0815/9/4a/019. PMID: 3240638.

47: Benabid AL, de Rougemont J, Decorps M, Remy C, Le Bas JF, Chauvin C, Leviel JL, Nissou MF, Jacrot M, Mouriquand C, et al. Etudes correlatives multiples sur biopsies stéréotaxiques de tumeurs cérébrales [Multiple correlative studies of stereotaxic biopsies of brain tumors]. Rev Electroencephalogr Neurophysiol Clin. 1987 Dec;17(4):401-10. French. doi: 10.1016/s0370-4475(87)80086-2. PMID: 2449708.

48: Arkhimova NA, Melikian AG. Elektrosubkortikografiia i impedans pri komp'iuterno-tomograficheskoĭ biopsii opukholeĭ golovnogo mozga [Electrosubcorticography and impedance in the computer tomographic biopsy of brain tumors]. Zh Vopr Neirokhir Im N N Burdenko. 1987 May-Jun;(3):30-4. Russian. PMID: 3307251.

49: Bullard DE, Makachinas TT. Measurement of tissue impedence in conjunction with computed tomography-guided stereotaxic biopsies. J Neurol Neurosurg Psychiatry. 1987 Jan;50(1):43-51. doi: 10.1136/jnnp.50.1.43. PMID: 3546598; PMCID: PMC1033248.

50: Le Bas JF, Leviel JL, Decorps M, Benabid AL. NMR relaxation times from serial stereotactic biopsies

in human brain tumors. J Comput Assist Tomogr. 1984 Dec;8(6):1048-57. doi: 10.1097/00004728-198412000-00002. PMID: 6389619.

1)

Zhang Z, Zhang L, Zhu J, Dong J, Liu H. Effect of electrical impedance-guided PEEP in reducing pulmonary complications after craniotomy: study protocol for a randomized controlled trial. Trials. 2022 Oct 1;23(1):837. doi: 10.1186/s13063-022-06751-6. PMID: 36183099.