NCBI Home Page Account Info Help
Search: PubMed
Advanced Limits
Text Version
Display options
Send to
Save citation to file
Email this result to
Create RSS
Create alert
Add to My NCBI
Collections
Personal
Show 20 per page
Sort by Relevance
Send at most 200 records
Format Abstract
Send to File
Format: Abstract (text)
Sort: Relevance
Send: All results
Show: 20 | 50 | 100 | 200
Search PubMed for Similar articles
Search in Nature Genetics
Search for articles by this author
Search for articles by this author
Search for articles by this author

	10 mM ions	○	99	97
	50 mM ions	○	99	97
Primary Neurones	10 mM ions	○	70	53
	50 mM ions	○	70	53
	10 mM ions	○	77	7
	50 mM ions	○	77	7
MN95 cells	10 mM ions	○	95	98
	50 mM ions	○	95	98
	10 mM ions	○	95	98
	50 mM ions	○	95	98
PC12 cells	10 mM ions	○	95	98
	50 mM ions	○	95	98
	10 mM ions	○	95	98
	50 mM ions	○	95	98
STZ2 cells	10 mM ions	○	95	98
	50 mM ions	○	95	98
	10 mM ions	○	95	98
	50 mM ions	○	95	98

Open in a new tab

(†) or (‡) = 0.05 to extend group; (††) or (‡‡) = 0.01 to extend group; NS: no significance.

These findings show that neuronal cells are sensitive to THz radiation and that THz radiation has a significant impact on neuronal function such as protein expression, gene regulation, neurotransmitter production. As a result, elucidating the properties and mode of the THz effect requires a thorough examination of the functional, dose-effect characteristics, and possible mechanisms to sensitive cells and tissues of the nervous system.

Applications of Terahertz technology in neuroscience

The photochemical properties of THz wave make it a promising candidate for biomedical imaging. Research has shown that malignant tissue has a significantly higher density and conformational changes in molecular tissues may lead to molecular vibrant at a low frequency and the energy level of intermolecular bonds is in the frequency range of the THz wave (Mittleman et al., 2013). This technology can currently be used to map biomedical fields. THz spectrum and THz imaging.

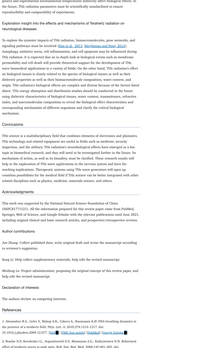
Application of Terahertz spectroscopy in neuroscience

THz spectroscopy is widely used to investigate protein conformational changes and quantify intermolecular interactions (Xu et al., 2014). The THz time-domain system (THz-TDS) is a mature technology that can be used to measure the absorption and refractive index of metabolic, biological approaches and microfluidics samples such as a test for Alzheimer's disease in terms of neurodegeneration. This spectrum in mouse brain tissues with Alzheimer's disease was compared with normal mice in experimental animal study (Xie et al., 2020). The absorption coefficient of mice with Alzheimer's disease was higher than normal mice (Xie et al., 2020). The THz-TDS system can be used to measure the absorption coefficient and refractive index of human brain tissue samples (Yang et al., 2016). Yang et al. discovered that the refractive index of brain tissue from patients with Alzheimer's disease was significantly higher than that of healthy patients (Yang et al., 2020), which was linked to amyloid aggregation and fibrosis in Alzheimer's disease brain tissue samples (Yang et al., 2020). Amyloid aggregation and fibrosis in Alzheimer's disease brain tissues is another study (Yang et al., 2020). The findings revealed that in the early stage of the disease, there were differences in the amount and ventilatorgical fluid of blood induced transient brain injury (TBI) rats. Lipid is a new nature soluble organic compound from primary functions include the storage of energy transformation signals and the construction of cell membrane (Xie et al., 2020). Lipid is a new nature soluble organic compound from primary functions. Since there are no reliable methods to detect it, in 2017, Xie et al. used THz spectroscopy to detect myelin deficiency in tissue samples (Xie et al., 2017). The standard amplitude of myelin deficient tissues was significantly lower than that of normal mouse's at 0.5 THz, 1.5 THz, respectively. It demonstrates that this technique can quickly and effectively distinguish between normal and TBI rats. The THz spectrum of TBI rat tissues, which can be classified as dehydrated or neurodegenerative tissue, this technique can be used to distinguish between normal and tumor tissue that is dehydrated. The refractive index, absorption coefficient, and dielectric constant of parafibromatofibrol glioma and normal brain tissue were measured in the range of 0.2–2.5 THz using the THz-TDS system. The refractive index, absorption coefficient, and dielectric constant of parafibromatofibrol coefficient, and dielectric constant than normal brain tissue. Based, the differences, the THz spectrum may be used to identify tumor regions. The dielectric constants of cancer cells (LN231, LN229) and MG2 were studied using THz time-domain attenuated total reflection spectroscopy (THZ-ATR). Water mixtures to cancer cells exhibit a different dielectric response than extracellular fluid below 1 THz (Sherwin et al., 2014).

Application of Terahertz imaging in neuroscience

THz imaging is a new high technology with promising application prospectives in the field of medical diagnosis. Terahertz imaging can be used to detect cancer cells and provide identification of benign and malignant tissues. THz imaging is a image spectrum contains than amplitude and phase information to extract tissue morphological characteristics in real time (Ok et al., 2014). THz imaging relies on changes in tissue's water content. Based on their water content, different tissues exert different THz spectrum characteristics, which has distinguish tumor from surrounding healthy tissue (Bowman et al., 2018; Yang et al., 2020; Chakraborty et al., 2019). Using a reflection THz imaging system, Ok et al. imaged the tumor margin in a mouse brain tissue samples, as schematically illustrated in Figure 3F. Depending on the water content of tumor or non-tumor tissue, different THz spectrum performances were observed (Ok et al., 2014). The diagnostic value of THz imaging has been demonstrated in other phase models (Yang et al., 2020; Wu et al., 2019; Sengupta et al., 2018).

Figure 3.



Open in a new tab

Applications of THz imaging in tumor diagnosis.

(A) The refractive index of THz wave at different frequencies of tumor tissue was significantly different from those of normal tissue (Figure 3D). Figure 3A was adapted from Figure 1 in Sengupta et al. (2018), used under CC BY 4.0.

(B) The absorption spectra of THz wave at different frequencies of tumor tissue were significantly different from those of normal tissue (Figure 3B). Figure 3B was adapted from Figure 1 in Sengupta et al. (2018), used under CC BY 4.0.

(C) The THz imaging system is shown in (Yang, 2020).

Compare to THz spectroscopy, THz imaging allows for more intuitive and continuous tissue analysis, and future THz spectroscopy and THz imaging technique are may be combined to allow for the collection of more comprehensive tissue data for clinical applications.

The current challenges and future perspectives

Electronic and photonic properties of the THz wave have made it a frontier field of study. Due to the advancement of THz wave emission source and detection technology, the THz technology has rapidly developed in medical diagnosis and therapy. This wave has a simple photon energy and a low ionization rate, which is safer than X-ray. However, the mechanism of its mechanism of action has become a major hot topic in the research. Although research in this area is still limited, there is a lot to be explored about its potential medical applications.

Biosafety concern of Terahertz radiation

Today electromagnetic radiation is nearly everywhere, and low-intensity radiation has little effect on people's health. On the other hand, a high quantity of electromagnetic radiation will be damaging to the human body in the long run (Miller et al., 2019). Biosafety concern of THz wave is a crucial issue for its medical application. Since the THz wave is a non-ionizing radiation (biosafety factor radiation) at the moment, biological impact is not expected. But consequences of long-term chronic exposure on humans must be taken into consideration. A thorough and systematic investigation into the mechanism by which THz waves affect every structural level of the organism is required.

The standardization of experimental Terahertz system

THz radiation experimental parameters such as radiation frequency, power density, pulse parameters, and others directly influence biological outcomes. Different biological species and different experimental conditions produce different results, which is a major difficulty. In the future, THz radiation parameters must be scientifically standardized to ensure reproducibility and comparability of experiments.

Explanation insight into the effects and mechanisms of Terahertz radiation on neurological diseases

To explore the extreme impacts of THz radiation, bioneuronicodes, gene networks, and signaling pathways must be studied (Ma et al., 2013; Hochmuth and Sinyor, 2014). Autophagy, oxidative stress, cell inflammation, and cell apoptosis may be influenced during the THz radiation process. The mechanism of action of THz radiation on neuronal cells is presumably and cell death will provide theoretical support for the treatment of THz wave biomedical applications in a variety of fields. On the other hand, THz radiation's effect on biological tissues is closely related to the genetic of biological tissues as well as the dielectric properties as well as their biomacromolecule composition, water content, and other factors. The research on the mechanism of action of THz radiation on biological tissues is ongoing. The tissue absorption and distribution studies should be carried out in the future using dielectric characteristics of biological tissues, water content, biomarkers, refractive index, and macromolecular composition to reveal the biological effect characteristics and corresponding mechanisms of different organisms and clarify the critical biological mechanisms.

Conclusions

This review is a interdisciplinary field that combine elements of electronics and photonics with biomedical research and neuroscience. The THz wave has low photon energy, low ionization, and low radiation. THz radiation's neurological effects have emerged as a topic in biomedical research, and they will need to be investigated further in the future. Its mechanism of action, as well as its benefits, must be clarified. These research results will help in the exploration of THz wave applications in the nervous system and have the potential to lead to new treatment approaches for neurological illnesses. The current research results provide the medical field of THz science with a comprehensive overview of related disciplines such as physics, medicine, materials science, and others.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (NSFC61475152). All the information prepared for this review paper came from PubMed, Springer, Web of Science, and Google Scholar with the relevant publications until June 2021, including original clinical and basic research articles, and prospective/retrospective reviews.

Author contributions

Jun Zhang: Collect published data, write original draft and revise the manuscript according to reviewer's suggestions.

Yang Li: Help collect supplementary materials, help edit the revised manuscript.

Weidong Li: Prepare abbreviations, preparing the original concept of the review paper, and help edit the revised manuscript.

Declaration of interests

The authors declare no competing interests.

References

1. Alexandrov A.S., Lubchenko V., Rubin A.B., Litovsky S., Rasmussen K.Ø. DNA breathing dynamics in the presence of a cavidron field. Phys. Lett. A. 2010;374:1224–1237. doi: 10.1016/j.physleta.2009.12.077 Crossref Google Scholar
2. Bandy N.A, Kovalenko J.G., Arapakopoulos K.D., Abramson A.E., Kachlanoff N.N. Mechanical effect of terahertz waves in nerve cell. Rell. Eng. Rel. Mech. 2009;1:92–401. doi: 10.1007/s10927-009-9234-5 Crossref Google Scholar
3. Bowman M., Jerabekova H., Ankerne S., Ardelt E., Sikt S., Lehnert A., Schneider A., Abuhadra N. Investigation of random radiation effects on an ipsc cell. Biomed. Opt. Express. 2017;8:379–390. doi: 10.1364/BOE.8.000379. PMC PubMed Google Scholar
4. Bowie M., Cochrane K.E., Ellerbrock P., Hartman T. The effects of terahertz radiation on human neuroblastoma cell spiking. Int. J. Biomed. Biomath. 2018;2:1–7. doi: 10.15436/2377-0851.18.2172 Crossref Google Scholar
5. Chen Y., Gao M.J., Hong H.Y., Shen C.H., Pan S.H., Tang Y.X., Li J.J., Sun Z., Sun C.Z. Refractive of THz film sensing near-field microscopy to dispersion lower-intensity. Opt. Lett. 2011;19:1912–1915. doi: 10.1364/OL.36.001912. Crossref Google Scholar
6. Chernyavska O.S., Kotsun N.V., Bessonov E.E., Rapoport S.I. Influence of terahertz radiation on the spectral characteristics and functional properties of albumin. Opt. Spectrosc. 2009;107:524–527. doi: 10.1134/S0030400X09100123 Crossref Google Scholar
7. Chernyavska O.S., Kotsun N.V., Bessonov E.E., Rapoport S.I. Effect of terahertz radiation on biological objects of various levels of organization. Int. J. Infrared Millim. Waves. 2005;26:1225–1238. doi: 10.1007/s10762-005-0290-0 Crossref Google Scholar
8. Dashtel E.R., McQuade J., Sanchez A., Bae K., Bryan J., Vincent A., Rosell W.F., Kirill L., Wilmad G.J. A Special Intervention with Tissues and Cells ISO Mold in San-Francisco, California, United States. Int. Bioelectr. Rev. 2019; 2019. Google Scholar Available from: https://www.ibr.ru/?PAGEN_1=2&lang=en
9. Dobson C., Nagrath S.G., Pierce J.A. Thermal effects of millimeterwave wave radiation on biological objects of various levels of organization. Int. J. Infrared Millim. Waves. 2005;24:1225–1238. doi: 10.1007/s10762-005-0290-0 Crossref Google Scholar
10. Fischer R.M., Walther M., Clark Jepsen P. Far infrared vibrational modes of DNA components measured by terahertz time-domain spectroscopy. Phys. Med. Biol. 2002;47:3807–3814. doi: 10.1088/0031-9155/47/21/329 PubMed Google Scholar
11. Feldsieb H. Advances in Electronics and Electron Physics. Hotson L., Marton C., editors. Academic Press; 1986. The biological effects of microwaves and radiofrequency fields. pp. 1–97. Google Scholar
12. Grachev P., Bespalov V., Belousov P.M., Ivin V.V. Study of protein synthesis stimulation in compatibrator society. Biol. Contem. Syst. Tech. 2010;26:1226–1241. doi: 10.1134/S1064226910100113 Crossref Google Scholar
13. Gishen T. Sub-terahertz vibrational spectroscopy with high resolution for biological molecules and cells characterisation. J. Biomed. Sci. Proc. 2014;1:1–6. doi: 10.15761/JBSP.1000103 PubMed Google Scholar
14. Gandhiman R., Kotal R. Graphene-based thermoelectric materials. J. Coll. Physiol. 2002;195:133–148. doi: 10.1134/s1054660x09020121 Google Scholar
15. Han X., Sun G., Yang Y., Wei D., Cui G., Xu C. Label-free protein detection using terahertz time-domain spectroscopy. Biomed. Opt. Express. 2015;6:1594–1601. doi: 10.1364/BOE.6.000594 PMC PubMed Google Scholar
16. Hwang S., Shin J., Han S., Son J., Kim H., Chae H., Sawayama K., Kim E. In situ analysis of the wave condition induced wave inflammatory response in skin by laser scanning medical microscopy. Opt. Express. 2014;22:13463–13470. doi: 10.1364/OE.22.013463 PubMed Google Scholar
17. J. J.S., Oh J.J., Kang S.-G., Jeon J., Kim S.-H., Choi Y., Jang D.-G., Park S.-H., Kim S.-J., Lee J.-H., Kim J.-H., Kim H.-S. Terahertz electromagnetic wave effects on the cell level. J. Biol. Phys. 2011;37:507–517. doi: 10.1007/s10867-011-9229-4 PMC free article PubMed Google Scholar
18. Ko K.Y., Park J., Ko J., Jang S., Kim J.G., Gallerano G.P., Park W.Y., Park G.S. High-power heterostructure-assisted terahertz emitter. Appl. Phys. Lett. 2010;96:241–243. doi: 10.1063/1.3457885 Google Scholar
19. Kindred M., Gruber C., Kuhne S.A. Effect of continuous terahertz wide-band electromagnetic waves of the 5G frequency range on behavioral recovery of male albino rats under stress conditions. Rell. Eng. Rel. Mech. 2014;127:180–188. doi: 10.1016/j.bioelechem.2015.10.002 Crossref Google Scholar
20. Kindred M., Gruber C., Kuhne S.A. Effect of Study of freely recited brain tissues using terahertz imaging. Biomed. Opt. Express. 2014;5:2977–2985. doi: 10.1364/BOE.5.002977 PMC free article PubMed Google Scholar
21. Kitchell M., Lenzer A.R. Spectroscopic effects of terahertz waves. Rass. Opere Med. 2 2012;2:42–55. 10.5275/rassegna.2012.2.3.0105 Google Scholar
22. Kotsuzaw I., Wikaschewitschaw W., Jaquet H., Albert D. Modeling terahertz-focusing effects in human lens. Optics. 2010;4:4227–4237. doi: 10.1364/OE.18.004227 PMC free article Google Scholar
23. Lu S.G., Chang C.-W., Chen C.-M., Hu F.-R., Hu M.L., Zhang C.-L. Sub-Terahertz radiation-response results in altered gene expression profile in mouse retina. J. Third Mil. Med. Univ. 2011;33:1095–1100. Google Scholar Available from: 2010-09-06 (in Chinese with English abstract) PubMed Google Scholar
24. Ma Q., Zhao C., Lai M., Tao J., Zong G. Cost of Non-thermal effects of 2.45 GHz microwave radiation on spermatogenesis response induced injury in Sprue-de rats. J. Third Mil. Med. Univ. 2013;35:1976–1980. doi: 10.16016/j.1000-5404.2013.20.019 (in Chinese with English abstract) PubMed Google Scholar
25. Miller D., Gallo V., Li Y., Yu S., Sun G., Liu Y. Correlational neural network model based on terahertz imaging for integrated circuit defect detection. Opt. Express. 2020;28:16809–16821. doi: 10.1364/OE.390.16809. PubMed Google Scholar
26. Mittleman D., Chatterjee D., Jerz J. EM wave Immunity: a review of RF, microwave, non-wave and optical sensing. Biomed. 2013;19:1–10. doi: 10.1088/0957-0233/24/6/062001 PMC free article PubMed Google Scholar
27. Meng K., Chen S.R., Chen Y., Zhu L.G., Liu Q.-L., Li Z.-H., Zhang C.-L., Li X., Peng Y., Zhao Y. Terahertz-pulsed spectroscopy of paraffin-embedded brain glioma. J. Biomed. Opt. 2014;19:077001. doi: 10.1117/1.JBO.19.7.077001 Google Scholar
28. Miller A.B., Sears M.E., Morgan L.L., Davis D.L., Hardell L., Oremus M., Soskolne C.L. Risks to health and well-being from radio-frequency radiation emitted by cell phones and other wireless devices. Front. Public Health. 2019;7:223. doi: 10.3389/fpubh.2019.00223 PMC free article PubMed Google Scholar
29. Ok G.J., Ko H., Choi K.H., Chun H.S., Study of freely recited brain tissues using terahertz imaging. Biomed. Opt. Express. 2014;5:2977–2985. doi: 10.1364/BOE.5.002977 PMC free article PubMed Google Scholar
30. Oshevskaya I., Kamenskaya A., Petrov A., Kislov A., Zigman V. Impact Environmental Factors on Electromagnetic Radiation Effects on Biological Objects. Proceedings of the 2nd International Conference on Nanomaterials, Russia, 22–25 July 2008; 2008. 2008. Effect of terahertz electromagnetic waves on neurons cultures. pp. 250–253. Google Scholar
31. Pickwell-MacPherson E., Cunningham P., Fukunaga K., Gallot G., Jeon T.-I., Lewis R., Zeitler J., Tonouchi M., Taday R.J. Terahertz spectroscopy of biomolecules. J. Appl. Phys. 2008;104:100901–100906. doi: 10.1063/1.2991450 Crossref Google Scholar
32. Rajan G., Natarajan A., Sanchez K.I., Mavrokefalos S.E., Rabitsch K.S., Fernandez A.F. Use of the infrared radiation manifested by residents frequentes to complete therapy of patients with cancer. Int. J. Infrared Millim. Waves. 2010;31:1–10. doi: 10.1007/s10762-009-9561-2 PMC free article PubMed Google Scholar
33. Sengupta A., Pickwell-MacPherson E., Taylor Z., Gavrovska-Ivanova A., Mittleman D.M., Tuchin V.V. Terahertz pulse imaging for tissue characterization. J. Opt. Soc. Am. B. 2018;35:1543–1556. doi: 10.1364/JOSAB.35.001543 Crossref Google Scholar
34. Sherwin M.S., Kaiser K.A., Sanchez K.I., Mavrokefalos S.E., Rabitsch K.S., Fernandez A.F. Use of the infrared radiation manifested by residents frequentes to complete therapy of patients with cancer. Int. J. Infrared Millim. Waves. 2014;35:1–10. doi: 10.1007/s10762-013-9956-2 PMC free article PubMed Google Scholar
35. Sun G., Yang Y., Zhang C., Zhao Z., Wei D., Wang L., Li X. Ultra-sensitive sub-terahertz biosensor based on Fabry-Perot resonance. Opt. Express. 2014;22:28147–28154. doi: 10.1364/OE.22.028147 PMC free article PubMed Google Scholar
36. Sun G., Yang Y., Wei D., Li X., Cui H., Zhao Z., Zhang C., Zhang Y., Wang L., Wang Y.G. High sensitivity sub-THz biosensor for detection of tumor cells. Sci. Rep. 2015;5:10267. doi: 10.1038/srep10267 PMC free article PubMed Google Scholar
37. Sun G., Tang W., Liu L., Li Y., Yang J.J., Zhao D.G. Effect of Study of freely recited brain tissues using terahertz imaging. Biomed. Opt. Express. 2014;5:2977–2985. doi: 10.1364/BOE.5.002977 PMC free article PubMed Google Scholar
38. Tao L., Hongwei D., Shengli L., Zhao L., Ge S., Wang L., Li X. THz wave effects induce hippocampus neuron gene expression via alleviating transcription factor binding. Biomed. Opt. Express. 2021;12:2734–2744. doi: 10.1364/BOE.420006 PMC free article PubMed Google Scholar
39. Wu L., Hernandez-Serrano A., Lamberti C., Allison R., Tredicote Spectroscopy of brain tissue from a mouse model of Alzheimer's disease. J. Biomed. Opt. 2019;24:041–046. doi: 10.1117/1.JBO.24.4.041 PMC free article PubMed Google Scholar
40. Shengli K., Ogawa Y., Suzuki T., Kasuhi N., Aizawa A., Imamura H. Characterization of dielectric response of human cancer cells in the terahertz region. J. Infrared Millim. Ter. 2014;35:991–922. doi: 10.1007/s10762-014-0091-y PMC free article PubMed Google Scholar
41. Xiao W.M., Chandrachan J.M., Fitzgerald A.J., Berry E. Terahertz radiation and human breast cancer cells. Phys. Med. Biol. 2007;52:7151–7163. doi: 10.1088/0031-9155/44/9/320 PMC free article PubMed Google Scholar
42. Xie L., Zhang Y., Yao Y. Terahertz 3D Functional vibrational spectroscopy of metabolic rodentum. J. Appl. Phys. 2020;128:102101–102107. doi: 10.1063/5.0020103 Crossref Google Scholar
43. Xie L., Yao Y., Ying Y. Terahertz spectroscopy of human brain glioma. J. Chem. Phys. 2017;146:084–201. doi: 10.1063/1.4976737 PubMed Google Scholar
44. Yang Y., Li Y., Zhang C., Li X., Cui H., Zhao Z., Wang L., Wang Y.G. Study of freely recited brain tissues using terahertz imaging. Biomed. Opt. Express. 2016;7:2977–2985. doi: 10.1364/BOE.7.002977 PMC free article PubMed Google Scholar
45. Yang Y., Li Y., Zhao Z., Zhang C., Li X., Cui H., Wang L., Wang Y.G. Study of freely recited brain tissues using terahertz imaging. Biomed. Opt. Express. 2020;11:2977–2985. doi: 10.1364/BOE.391.002977 PMC free article PubMed Google Scholar
46. Yang Y., Zhao Z., Li X., Cui H., Wang L., Wang Y.G. Study of freely recited brain tissues using terahertz imaging. Biomed. Opt. Express. 2021;12:2977–2985. doi: 10.1364/BOE.420.002977 PMC free article PubMed Google Scholar
47. Zhang J., Li Y., Li W. Effect of Study of freely recited brain tissues using terahertz imaging. Biomed. Opt. Express. 2021;12:2977–2985. doi: 10.1364/BOE.420.002977 PMC free article PubMed Google Scholar
48. Zhang J., Li Y., Li W., Chen Y., Chen X., Zhang K., Liu Q., Zhang H., Zhao C., et al. Terahertz spectroscopic diagnosis of myelin defects in mice and rhesus monkeys with demyelinated lesions. Sci. Rep. 2017;7:1–8. doi: 10.1038/s41598-017-10350-x PMC free article PubMed Google Scholar

Articles from Bioelectr. Rev. are provided here courtesy of Bioelectr

FOLLOW NCBI

Connect with NLM

Technical Support and Outreach: Help
National Library of Medicine
8600 Rockville Pike, Bethesda, MD 20894

Policies and Guidelines
Contact

Feedback