Journal of Functional Biomaterials • *Open Access* • Volume 12, Issue 4 • December 2021 • Article number 59

Document type
Review • *Gold Open Access* • *Green Open Access*

Source type
Journal

ISSN
20794983

DOI
10.3390/jfb12040059

View more

Functionalized antimicrobial nanofibers: Design criteria and recent advances

Hamdan N.[a], Yamin A.[a], Hamid S.A.[a, b], Khodir W.K.W.A.[a, b], Guarino V.[c]

Save all to author list

[a] Department of Chemistry, Kulliyyah of Science, International Islamic University Malaysia Kuantan Campus, Bandar Indera Mahkota, Kuantan, 25200, Malaysia

[b] SYNTOF, Kulliyyah of Science, International Islamic University Malaysia Kuantan Campus, Bandar Indera Mahkota, Kuantan, 25200, Malaysia

[c] Institute of Polymers, Composites and Biomaterials, National Research Council of Italy, Mostra d'Oltremare Pad.20, V.le J.F.Kennedy 54, Naples, 80125, Italy

Abstract

The rise of antibiotic resistance has become a major threat to human health and it is spreading globally. It can cause common infectious diseases to be difficult to treat and leads to higher medical costs and increased mortality. Hence, multifunctional polymeric nanofibers with distinctive structures and unique physiochemical properties have emerged as a neo-tool to target biofilm and overcome deadly bacterial infections. This review emphasizes electrospun nanofibers' design criteria and properties that can be utilized to enhance their therapeutic activity for antimicrobial therapy. Also, we present recent progress in designing the surface functionalization of antimicrobial nanofibers with non-antibiotic agents for effective antibacterial therapy. Lastly, we discuss the future trends and remaining challenges for polymeric nanofibers . © 2021 by the authors. Licensee MDPI, Basel, Switzerland.

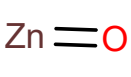
Author keywords

Antimicrobial resistance; Electrospinning; Nanofibers ; Non-antibiotic treatments; Surface functionalization

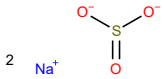
Reaxys Chemistry database information

Substances

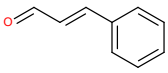
View all substances (6)



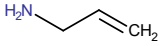
View details



View details



View details



View details

Powered by Reaxys

SciVal Topics

Metrics

Funding details

References (239)

View in search results format >

All

Export Print E-mail Save to PDF Create bibliography

1 (2019) *Antibiotic Resistance Threats in the United States*. Cited 1154 times. Centers for Disease Control Prevention Centre (CDC). (accessed on 9 September 2021) https://www.cdc.gov/drugresistance/pdf/threats-report/2019-ar-threats-report-508.pdf

2 Ventola, C.L.
The antibiotic resistance crisis: Part 1: causes and threats

(2015) *P and T*, 40 (4), pp. 277-283. Cited 2276 times. http://www.ptcommunity.com/system/files/pdf/ptj4004277.pdf

View at Publisher

3 Sprenger, M., Fukuda, K.

New mechanisms, new worries

(2016) *Science*, 351 (6279), pp. 1263-1264. Cited 32 times.
http://science.sciencemag.org/content/sci/351/6279/1263.full.pdf
doi: 10.1126/science.aad9450

View at Publisher

4 Kraemer, S.A., Ramachandran, A., Perron, G.G.

Antibiotic pollution in the environment: From microbial ecology to public policy (Open Access)

(2019) *Microorganisms*, 7 (6), art. no. 180. Cited 184 times.
https://www.mdpi.com/2076-2607/7/6/180/pdf
doi: 10.3390/microorganisms7060180

View at Publisher

5 Munita, J.M., Arias, C.A.

Mechanisms of antibiotic resistance (Open Access)

(2016) *Microbiology Spectrum*, 4 (2), art. no. VMBF-0016-2015. Cited 697 times.
http://www.asmscience.org/docserver/fulltext/microbiolspec/4/2/VMBF-0016-2015.pdf?expires=1486108180&id=id&accname=45052&checksum=43A031364F99D87142C9C34E0F0E2DC9
doi: 10.1128/microbiolspec.VMBF-0016-2015

View at Publisher

6 Blair, J.M.A., Webber, M.A., Baylay, A.J., Ogbolu, D.O., Piddock, L.J.V.

Molecular mechanisms of antibiotic resistance

(2015) *Nature Reviews Microbiology*, 13 (1), pp. 42-51. Cited 1624 times.
http://www.nature.com/nrmicro/index.html
doi: 10.1038/nrmicro3380

View at Publisher

7 Kadhum, H.A., Hasan, T.H.

The study of bacillus subtils antimicrobial activity on some of the pathological isolates

(2019) *International Journal of Drug Delivery Technology*, 9 (2), pp. 193-196. Cited 5 times.
http://impactfactor.org/PDF/IJDDT/9/IJDDT,Vol9,Issue2,Article12.pdf
doi: 10.25258/ijddt.9.2.12

View at Publisher

8 Henrichfreise, B., Wiegand, I., Pfister, W., Wiedemann, B.

Resistance mechanisms of multiresistant Pseudomonas aeruginosa strains from Germany and correlation with hypermutation (Open Access)

(2007) *Antimicrobial Agents and Chemotherapy*, 51 (11), pp. 4062-4070. Cited 138 times.
doi: 10.1128/AAC.00148-07

View at Publisher

9 Makabenta, J.M.V., Nabawy, A., Li, C.-H., Schmidt-Malan, S., Patel, R., Rotello, V.M.

Nanomaterial-based therapeutics for antibiotic-resistant bacterial infections

(2021) *Nature Reviews Microbiology*, 19 (1), pp. 23-36. Cited 77 times.
http://www.nature.com/nrmicro/index.html
doi: 10.1038/s41579-020-0420-1

View at Publisher

10 Pang, Z., Raudonis, R., Glick, B.R., Lin, T.-J., Cheng, Z.

Antibiotic resistance in Pseudomonas aeruginosa: mechanisms and alternative therapeutic strategies (Open Access)

(2019) *Biotechnology Advances*, 37 (1), pp. 177-192. Cited 338 times.
www.elsevier.com/inca/publications/store/5/2/5/4/5/5/index.htt
doi: 10.1016/j.biotechadv.2018.11.013

View at Publisher

11 Sandoval-Motta, S., Aldana, M.

Adaptive resistance to antibiotics in bacteria: A systems biology perspective

(2016) *Wiley Interdisciplinary Reviews: Systems Biology and Medicine*, 8 (3), pp. 253-267. Cited 31 times.
http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1939-005X
doi: 10.1002/wsbm.1335

View at Publisher

12 Rasouli, R., Barhoum, A., Bechelany, M., Dufresne, A.

Nanofibers for Biomedical and Healthcare Applications (Open Access)

(2019) *Macromolecular Bioscience*, 19 (2), art. no. 1800256. Cited 74 times.
http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1616-5195
doi: 10.1002/mabi.201800256

View at Publisher

13 Namdari, M., Eatemadi, A.

Nanofibrous bioengineered heart valve—Application in paediatric medicine

(2016) *Biomedicine and Pharmacotherapy*, 84, pp. 1179-1188. Cited 18 times.
www.elsevier.com/locate/biomedpharm
doi: 10.1016/j.biopha.2016.10.058

View at Publisher

14 Farnaz-Sadat, F., Khoddami, A., Avinc, O.
Poly(lactic acid) (PLA) Nanofibers for Bone Tissue Engineering
(2019) *J. Text Polym*, 7, p. 47. Cited 9 times.

15 Obregón, R., Ramón-Azcón, J., Ahadian, S.

Nanofiber composites in blood vessel tissue engineering

(2017) *Nanofiber Composites for Biomedical Applications*, pp. 483-506. Cited 7 times.
http://www.sciencedirect.com/science/book/9780081001738
ISBN: 978-008100208-7; 978-008100173-8
doi: 10.1016/B978-0-08-100173-8.00019-3

View at Publisher

16 Liu, Y., Zhou, S., Gao, Y., Zhai, Y.

Electrospun nanofibers as a wound dressing for treating diabetic foot ulcer (Open Access)

(2019) *Asian Journal of Pharmaceutical Sciences*, 14 (2), pp. 130-143. Cited 70 times.
http://www.journals.elsevier.com/asian-journal-of-pharmaceutical-sciences/recent-articles/
doi: 10.1016/j.ajps.2018.04.004

View at Publisher

17 Homaeigohar, S., Boccaccini, A.R.

Antibacterial biohybrid nanofibers for wound dressings (Open Access)

(2020) *Acta Biomaterialia*, 107, pp. 25-49. Cited 133 times.
http://www.journals.elsevier.com/acta-biomaterialia
doi: 10.1016/j.actbio.2020.02.022

View at Publisher

18 Jingcheng, L., Reddy, V.S., Jayathilaka, W.A.D.M., Chinnappan, A., Ramakrishna, S., Ghosh, R.

Intelligent polymers, fibers and applications (Open Access)

(2021) *Polymers*, 13 (9), art. no. 1427. Cited 3 times.
https://www.mdpi.com/2073-4360/13/9/1427/pdf
doi: 10.3390/polym13091427

View at Publisher

19 Ambekar, R.S., Kandasubramanian, B.

Advancements in nanofibers for wound dressing: A review

(2019) *European Polymer Journal*, 117, pp. 304-336. Cited 99 times.
https://www.journals.elsevier.com/european-polymer-journal
doi: 10.1016/j.eurpolymj.2019.05.020

View at Publisher

20 Wang, X., Hsiao, B.S.

Electrospun nanofiber membranes (Open Access)

(2016) *Current Opinion in Chemical Engineering*, 12, pp. 62-81. Cited 124 times.
http://www.elsevier.com/wps/find/journaldescription.cws_home/725837/description#description
doi: 10.1016/j.coche.2016.03.001

View at Publisher

21 Pires, L.R., Guarino, V., Oliveira, M.J., Ribeiro, C.C., Barbosa, M.A., Ambrosio, L., Pêgo, A.P.

Ibuprofen-loaded poly(trimethylene carbonate-co-ε-caprolactone) electrospun fibres for nerve regeneration (Open Access)

(2016) *Journal of Tissue Engineering and Regenerative Medicine*, 10 (3), pp. E154-E166. Cited 34 times.
http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1932-7005
doi: 10.1002/term.1792

View at Publisher

22 Akhmetova, A., Heinz, A.

Electrospinning proteins for wound healing purposes: Opportunities and challenges (Open Access)

(2021) *Pharmaceutics*, 13 (1), art. no. 4, pp. 1-22. Cited 13 times.
https://www.mdpi.com/1999-4923/13/1/20
doi: 10.3390/pharmaceutics13010004

View at Publisher

23 Juncos Bombin, A.D., Dunne, N.J., McCarthy, H.O.

Electrospinning of natural polymers for the production of nanofibres for wound healing applications

(2020) *Materials Science and Engineering C*, 114, art. no. 110994. Cited 46 times.
https://www.journals.elsevier.com/materials-science-and-engineering-c
doi: 10.1016/j.msec.2020.110994

View at Publisher

24 Sabra, S., Ragab, D.M., Agwa, M.M., Rohani, S.

Recent advances in electrospun nanofibers for some biomedical applications

(2020) *European Journal of Pharmaceutical Sciences*, 144, art. no. 105224. Cited 31 times.
www.elsevier.com/locate/ejps
doi: 10.1016/j.ejps.2020.105224

View at Publisher

25 Almasi, H., Jafarzadeh, P., Mehryar, L.

Fabrication of novel nanohybrids by impregnation of CuO nanoparticles into bacterial cellulose and chitosan nanofibers: Characterization, antimicrobial and release properties

(2018) *Carbohydrate Polymers*, 186, pp. 273-281. Cited 78 times.
http://www.elsevier.com/wps/find/journaldescription.cws_home/405871/description#description
doi: 10.1016/j.carbpol.2018.01.067

View at Publisher

26 Sebe, I., Szabó, B., Nagy, Z.K., Szabó, D., Zsidai, L., Kocsis, B., Zelkó, R.

Polymer structure and antimicrobial activity of polyvinylpyrrolidone-based iodine nanofibers prepared with high-speed rotary spinning technique

(2013) *International Journal of Pharmaceutics*, 458 (1), pp. 99-103. Cited 55 times.
doi: 10.1016/j.ijpharm.2013.10.011

View at Publisher

27 Shahriar, S.M.S., Mondal, J., Hasan, M.N., Revuri, V., Lee, D.Y., Lee, Y.-K.

Electrospinning nanofibers for therapeutics delivery (Open Access)

(2019) *Nanomaterials*, 9 (4), art. no. 532. Cited 76 times.
https://www.mdpi.com/2079-4991/9/4/532/pdf
doi: 10.3390/nano9040532

View at Publisher

28 Arampatzis, A.S., Kontogiannopoulos, K.N., Theodoridis, K., Aggelidou, E., Rat, A., Willems, A., Tsivintzelis, I., (...), Assimopoulou, A.N.

Electrospun wound dressings containing bioactive natural products: physico-chemical characterization and biological assessment (Open Access)

(2021) *Biomaterials Research*, 25 (1), art. no. 23. Cited 2 times.
biomaterialsres.biomedcentral.com/
doi: 10.1186/s40824-021-00223-9

View at Publisher

29 Wang, S.-D., Ma, Q., Wang, K., Chen, H.-W.

Improving Antibacterial Activity and Biocompatibility of Bioinspired Electrospinning Silk Fibroin Nanofibers Modified by Graphene Oxide (Open Access)

(2017) *ACS Omega*, 3 (1), pp. 406-413. Cited 63 times.
pubs.acs.org/journal/acsodf
doi: 10.1021/acsomega.7b01210

View at Publisher

30 Valentini, F., Calcaterra, A., Ruggiero, V., Pichichero, E., Martino, A., Iosi, F., Bertuccini, L., (...), Talamo, M.

Functionalized Graphene Derivatives: Antibacterial Properties and Cytotoxicity (Open Access)

(2019) *Journal of Nanomaterials*, 2019, art. no. 2752539. Cited 17 times.
http://www.hindawi.com/journals/jnm/
doi: 10.1155/2019/2752539

View at Publisher

31 Yadav, R., Balasubramanian, K.

Bioabsorbable Engineered Nanobiomaterials for Antibacterial Therapy

(2016) *Engineering of Nanobiomaterials: Applications of Nanobiomaterials*, pp. 77-117. Cited 10 times.
http://www.sciencedirect.com/science/book/9780323415323
ISBN: 978-032341734-1; 978-032341532-3
doi: 10.1016/B978-0-323-41532-3.00003-8

View at Publisher

32 Abrigo, M., McArthur, S.L., Kingshott, P.

Electrospun nanofibers as dressings for chronic wound care: Advances, challenges, and future prospects

(2014) *Macromolecular Bioscience*, 14 (6), pp. 772-792. Cited 318 times.
http://www3.interscience.wiley.com/journal/77002860/home
doi: 10.1002/mabi.201300561

View at Publisher

33 Cheng, G., Dai, J., Dai, J., Wang, H., Chen, S., liu, Y., Liu, X., (...), Li, Z.

Extracellular matrix imitation utilizing nanofibers-embedded biomimetic scaffolds for facilitating cartilage regeneration

(2021) *Chemical Engineering Journal*, 410, art. no. 128379. Cited 5 times.
www.elsevier.com/inca/publications/store/6/0/1/2/7/3/index.htt
doi: 10.1016/j.cej.2020.128379

View at Publisher

34 Hu, F., Zhang, X., Liu, H., Xu, P., Doulathunnisa, Teng, G., Xiao, Z.

Neuronally differentiated adipose-derived stem cells and aligned PHBV nanofiber nerve scaffolds promote sciatic nerve regeneration

(2017) *Biochemical and Biophysical Research Communications*, 489 (2), pp. 171-178. Cited 34 times.
http://www.sciencedirect.com/science/journal/0006291X
doi: 10.1016/j.bbrc.2017.05.119

View at Publisher

35 Levengood, S.L., Erickson, A.E., Chang, F.-C., Zhang, M.

Chitosan-poly(caprolactone) nanofibers for skin repair (Open Access)

(2017) *Journal of Materials Chemistry B*, 5 (9), pp. 1822-1833. Cited 60 times.
http://pubs.rsc.org/en/journals/journalissues/tb
doi: 10.1039/C6TB03223K

View at Publisher

36 Alven, S., Buyana, B., Feketshane, Z., Aderibigbe, B.A.

Electrospun nanofibers/nanofibrous scaffolds loaded with silver nanoparticles as effective antibacterial wound dressing materials (Open Access)

(2021) *Pharmaceutics*, 13 (7), art. no. 964. Cited 5 times.
https://www.mdpi.com/1999-4923/13/7/964/pdf
doi: 10.3390/pharmaceutics13070964

View at Publisher

37 Wang, P.-Y., Ji, Q.-T., Xiang, H.-M., Zhang, T.-H., Zeng, D., Zhou, X., Chang, F., (...), Yang, S.

Assembling Anthracene-Tailored Amphiphiles: Charge-Transfer Interactions Directed Hierarchical Nanofibers with Ameliorative Antibacterial Activity toward Plant Pathogens

(2020) *Journal of Agricultural and Food Chemistry*, 68 (20), pp. 5579-5585. Cited 4 times.
http://pubs.acs.org/journal/jafcau
doi: 10.1021/acs.jafc.0c01991

View at Publisher

38 Guarino, V., Cirillo, V., Ambrosio, L.

Bicomponent electrospun scaffolds to design extracellular matrix tissue analogs

(2016) *Expert Review of Medical Devices*, 13 (1), pp. 83-102. Cited 35 times.
doi: 10.1586/17434440.2016.1126505

View at Publisher

39 Ferraris, S., Spriano, S., Scalia, A.C., Cochis, A., Rimondini, L., Cruz-Maya, I., Guarino, V., (...), Vineis, C.

Topographical and biomechanical guidance of electrospun fibers for biomedical applications (Open Access)

(2020) *Polymers*, 12 (12), art. no. 2896, pp. 1-32. Cited 9 times.
https://www.mdpi.com/2073-4360/12/12/2896/pdf
doi: 10.3390/polym12122896

View at Publisher

40 Saracino, E., Cirillo, V., Marrese, M., Guarino, V., Benfenati, V., Zamboni, R., Ambrosio, L.

Structural and functional properties of astrocytes on PCL based electrospun fibres (Open Access)

(2021) *Materials Science and Engineering C*, 118, art. no. 111363. Cited 8 times.
https://www.journals.elsevier.com/materials-science-and-engineering-c
doi: 10.1016/j.msec.2020.111363

View at Publisher

41 Rao, S.S., Nelson, M.T., Xue, R., DeJesus, J.K., Viapiano, M.S., Lannutti, J.J., Sarkar, A., (...), Winter, J.O.

Mimicking white matter tract topography using core-shell electrospun nanofibers to examine migration of malignant brain tumors (Open Access)

(2013) *Biomaterials*, 34 (21), pp. 5181-5190. Cited 81 times.
doi: 10.1016/j.biomaterials.2013.03.069

View at Publisher

42 Liu, X.-F., Zhang, J., Liu, J.-J., Zhou, Q.-H., Liu, Z., Hu, P.-Y., Yuan, Z., (...), Long, Y.-Z.

Bifunctional CuS composite nanofibers via in situ electrospinning for outdoor rapid hemostasis and simultaneous ablating superbug

(2020) *Chemical Engineering Journal*, 401, art. no. 126096. Cited 23 times.
www.elsevier.com/inca/publications/store/6/0/1/2/7/3/index.htt
doi: 10.1016/j.cej.2020.126096

View at Publisher

43 Xie, X., Li, D., Chen, Y., Shen, Y., Yu, F., Wang, W., Yuan, Z., (...), Mo, X.

Conjugate Electrospun 3D Gelatin Nanofiber Sponge for Rapid Hemostasis

(2021) *Advanced Healthcare Materials*, 10 (20), art. no. 2100918. Cited 2 times.
http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)2192-2659
doi: 10.1002/adhm.202100918

View at Publisher

44 Chen, S., Carlson, M.A., Zhang, Y.S., Hu, Y., Xie, J.

Fabrication of injectable and superelastic nanofiber rectangle matrices ("peanuts") and their potential applications in hemostasis (Open Access)

(2018) *Biomaterials*, 179, pp. 46-59. Cited 43 times.
http://www.journals.elsevier.com/biomaterials/
doi: 10.1016/j.biomaterials.2018.06.031

View at Publisher

45 Schoeller, J., Itel, F., Wuertz-Kozak, K., Gaiser, S., Luisier, N., Hegemann, D., Ferguson, S.J., (...), Rossi, R.M.

pH-responsive chitosan/alginate polyelectrolyte complexes on electrospun PLGA nanofibers for controlled drug release (Open Access)

(2021) *Nanomaterials*, 11 (7), art. no. 1850. Cited 5 times.
https://www.mdpi.com/2079-4991/11/7/1850/pdf
doi: 10.3390/nano11071850

View at Publisher

46 Udomluck, N., Lee, H., Hong, S., Lee, S.-H., Park, H.

Surface functionalization of dual growth factor on hydroxyapatite-coated nanofibers for bone tissue engineering

(2020) *Applied Surface Science*, 520, art. no. 146311. Cited 18 times.
http://www.journals.elsevier.com/applied-surface-science/
doi: 10.1016/j.apsusc.2020.146311

View at Publisher

47 Kowalczyk, T.

Functional micro- and nanofibers obtained by nonwoven post-modification (Open Access)

(2020) *Polymers*, 12 (5), art. no. 1087. Cited 8 times.
https://res.mdpi.com/d_attachment/polymers/polymers-12-01087/article_deploy/polymers-12-01087-v2.pdf
doi: 10.3390/POLYM12051087

View at Publisher

48 Ko, Y.-M., Choi, D.-Y., Jung, S.-C., Kim, B.-H.

Characteristics of plasma treated electrospun polycaprolactone (PCL) nanofiber scaffold for bone tissue engineering

(2015) *Journal of Nanoscience and Nanotechnology*, 15 (1), pp. 192-195. Cited 41 times.
http://docserver.ingentaconnect.com/deliver/connect/asp/15334880/v15n1/s28.pdf?expires=1420763923&id=80399705&titleid=4286&accname=Elsevier+BV&checksum=3C4212291A2A11C97C1D3CB1904F3036
doi: 10.1166/jnn.2015.8372

View at Publisher

49 Saini, S., Belgacem, M.N., Bras, J.

Effect of variable aminoalkyl chains on chemical grafting of cellulose nanofiber and their antimicrobial activity

(2017) *Materials Science and Engineering C*, 75, pp. 760-768. Cited 42 times.
doi: 10.1016/j.msec.2017.02.062

View at Publisher

50 Giram, P.S., Shitole, A., Nande, S.S., Sharma, N., Garnaik, B.

Fast dissolving moxifloxacin hydrochloride antibiotic drug from electrospun Eudragit L-100 nonwoven nanofibrous Mats

(2018) *Materials Science and Engineering C*, 92, pp. 526-539. Cited 30 times.
doi: 10.1016/j.msec.2018.06.031

View at Publisher

51 Keshvardoostchokami, M., Majidi, S.S., Huo, P., Ramachandran, R., Chen, M., Liu, B.

Electrospun nanofibers of natural and synthetic polymers as artificial extracellular matrix for tissue engineering (Open Access)

(2021) *Nanomaterials*, 11 (1), art. no. 21, pp. 1-23. Cited 17 times.
https://www.mdpi.com/2079-4991/11/1/21/pdf
doi: 10.3390/nano11010021

View at Publisher

52 Sundaramurthi, D., Krishnan, U.M., Sethuraman, S.

Electrospun nanofibers as scaffolds for skin tissue engineering

(2014) *Polymer Reviews*, 54 (2), pp. 348-376. Cited 143 times.
doi: 10.1080/15583724.2014.881374

View at Publisher

53 Li, X., Wang, L., Fan, Y., Feng, Q., Cui, F.-Z., Watari, F.
Nanostructured scaffolds for bone tissue engineering

(2013) *Journal of Biomedical Materials Research - Part A*, 101 A (8), pp. 2424-2435. Cited 244 times.
doi: 10.1002/jbm.a.34539

View at Publisher

54 Zhong, X., Li, R., Wang, Z., Wang, W., Yu, D.
Eco-fabrication of antibacterial nanofibrous membrane with high moisture permeability from wasted wool fabrics

(2020) *Waste Management*, 102, pp. 404-411. Cited 10 times.
www.elsevier.com/locate/wasman
doi: 10.1016/j.wasman.2019.11.005

View at Publisher

55 Gao, Y., Truong, Y.B., Zhu, Y., Louis Kyratzis, I.
Electrospun antibacterial nanofibers: Production, activity, and in vivo applications (Open Access)

(2014) *Journal of Applied Polymer Science*, 131 (18), art. no. 40797, pp. 9041-9053. Cited 104 times.
http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1097-4628
doi: 10.1002/app.40797

View at Publisher

56 Al-Enizi, A.M., Zagho, M.M., Elzatahry, A.A.
Polymer-based electrospun nanofibers for biomedical applications (Open Access)

(2018) *Nanomaterials*, 8 (4), art. no. 259. Cited 108 times.
http://www.mdpi.com/2079-4991/8/4/259/pdf
doi: 10.3390/nano8040259

View at Publisher

57 Ryšánek, P., Malý, M., Čapková, P., Kormunda, M., Kolská, Z., Gryndler, M., Novák, O., (...), Munzarová, M.
Antibacterial modification of nylon-6 nanofibers: structure, properties and antibacterial activity.

(2017) *Journal of Polymer Research*, 24 (11), art. no. 208. Cited 13 times.
doi: 10.1007/s10965-017-1365-6

View at Publisher

58 Ferraris, S., Guarino, V., Cochis, A., Varesano, A., Cruz Maya, I., Vineis, C., Rimondini, L., (...), Spriano, S.
Aligned keratin submicrometric-fibers for fibroblasts guidance onto nanogrooved titanium surfaces for transmucosal implants

(2018) *Materials Letters*, 229, pp. 1-4. Cited 10 times.
http://www.journals.elsevier.com/materials-letters/
doi: 10.1016/j.matlet.2018.06.103

View at Publisher

59 Castro Coelho, S., Nogueiro Estevinho, B., Rocha, F.

Encapsulation in food industry with emerging electrohydrodynamic techniques: Electrospinning and electrospraying – A review

(2021) *Food Chemistry*, 339, art. no. 127850. Cited 28 times.
www.elsevier.com/locate/foodchem
doi: 10.1016/j.foodchem.2020.127850

View at Publisher

60 Kurtz, I.S., Schiffman, J.D.

Current and emerging approaches to engineer antibacterial and antifouling electrospun nanofibers (Open Access)

(2018) *Materials*, 11 (7), art. no. 1059. Cited 39 times.
http://www.mdpi.com/1996-1944/11/7/1059/pdf
doi: 10.3390/ma11071059

View at Publisher

61 Anselme, K., Davidson, P., Popa, A.M., Giazzon, M., Liley, M., Ploux, L.

The interaction of cells and bacteria with surfaces structured at the nanometre scale

(2010) *Acta Biomaterialia*, 6 (10), pp. 3824-3846. Cited 599 times.
http://www.journals.elsevier.com/acta-biomaterialia
doi: 10.1016/j.actbio.2010.04.001

View at Publisher

62 Abrigo, M., Kingshott, P., McArthur, S.L.

Electrospun polystyrene fiber diameter influencing bacterial attachment, proliferation, and growth

(2015) *ACS Applied Materials and Interfaces*, 7 (14), pp. 7644-7652. Cited 55 times.
http://pubs.acs.org/journal/aamick
doi: 10.1021/acsami.5b00453

View at Publisher

63 Heidari, M., Bahrami, H., Ranjbar-Mohammadi, M.

Fabrication, optimization and characterization of electrospun poly(caprolactone)/gelatin/graphene nanofibrous mats

(2017) *Materials Science and Engineering C*, 78, pp. 218-229. Cited 50 times.
doi: 10.1016/j.msec.2017.04.095

View at Publisher

64 Heidari, M., Bahrami, S.H., Ranjbar-Mohammadi, M., Milan, P.B.

Smart electrospun nanofibers containing PCL/gelatin/graphene oxide for application in nerve tissue engineering

(2019) *Materials Science and Engineering C*, 103, art. no. 109768. Cited 64 times.
doi: 10.1016/j.msec.2019.109768

View at Publisher

65 Jalaja, K., Sreehari, V.S., Kumar, P.R.A., Nirmala, R.J.

Graphene oxide decorated electrospun gelatin nanofibers: Fabrication, properties and applications

(2016) *Materials Science and Engineering C*, 64, pp. 11-19. Cited 44 times.
doi: 10.1016/j.msec.2016.03.036

View at Publisher

66 Guarino, V., Cruz-Maya, I., Altobelli, R., Abdul Khodir, W.K., Ambrosio, L., Alvarez Pèrez, M.A., Flores, A.A.

Electrospun polycaprolactone nanofibres decorated by drug loaded chitosan nano-reservoirs for antibacterial treatments

(2017) *Nanotechnology*, 28 (50), art. no. 505103. Cited 18 times.
http://iopscience.iop.org/article/10.1088/1361-6528/aa9542/pdf
doi: 10.1088/1361-6528/aa9542

View at Publisher

67 Ravikumar, R., Ganesh, M., Ubaidulla, U., Young Choi, E., Tae Jang, H.

Preparation, characterization, and in vitro diffusion study of nonwoven electrospun nanofiber of curcumin-loaded cellulose acetate phthalate polymer (Open Access)

(2017) *Saudi Pharmaceutical Journal*, 25 (6), pp. 921-926. Cited 28 times.
http://www.sciencedirect.com/science/journal/13190164
doi: 10.1016/j.jsps.2017.02.004

View at Publisher

68 Bhattarai, R.S., Bachu, R.D., Boddu, S.H.S., Bhaduri, S.

Biomedical applications of electrospun nanofibers: Drug and nanoparticle delivery (Open Access)

(2019) *Pharmaceutics*, 11 (1), art. no. 5. Cited 94 times.
https://www.mdpi.com/1999-4923/11/1/5/pdf
doi: 10.3390/pharmaceutics11010005

View at Publisher

69 Lin, L., Gu, Y., Cui, H.

Moringa oil/chitosan nanoparticles embedded gelatin nanofibers for food packaging against Listeria monocytogenes and Staphylococcus aureus on cheese

(2019) *Food Packaging and Shelf Life*, 19, pp. 86-93. Cited 81 times.
http://www.journals.elsevier.com/food-packaging-and-shelf-life/
doi: 10.1016/j.fpsl.2018.12.005

View at Publisher

70 Bose, R.J.C., Arai, Y., Ahn, J.C., Park, H., Lee, S.-H.

Influence of cationic lipid concentration on properties of lipid–polymer hybrid nanospheres for gene delivery (Open Access)

(2015) *International Journal of Nanomedicine*, 10, pp. 5367-5382. Cited 37 times.
https://www.dovepress.com/getfile.php?fileID=26896
doi: 10.2147/IJN.S87120

View at Publisher

71 Persano, L., Camposeo, A., Tekmen, C., Pisignano, D.

Industrial upscaling of electrospinning and applications of polymer nanofibers: A review (Open Access)

(2013) *Macromolecular Materials and Engineering*, 298 (5), pp. 504-520. Cited 597 times.
doi: 10.1002/mame.201200290

View at Publisher

72 Kim, D.-H., Jang, J.-S., Koo, W.-T., Choi, S.-J., Kim, S.-J., Kim, I.-D.

Hierarchically interconnected porosity control of catalyst-loaded WO_3 nanofiber scaffold: Superior acetone sensing layers for exhaled breath analysis

(2018) *Sensors and Actuators, B: Chemical*, 259, pp. 616-625. Cited 37 times.
doi: 10.1016/j.snb.2017.12.051

View at Publisher

73 Feng, G., Cheng, Y., Wang, S.-Y., Borca-Tasciuc, D.A., Worobo, R.W., Moraru, C.I.

Bacterial attachment and biofilm formation on surfaces are reduced by small-diameter nanoscale pores: How small is small enough? (Open Access)

(2015) *npj Biofilms and Microbiomes*, 1, art. no. 15022. Cited 129 times.
https://www.nature.com/npjbiofilms/
doi: 10.1038/npjbiofilms.2015.22

View at Publisher

74 Chen, S., McCarthy, A., John, J.V., Su, Y., Xie, J.

Converting 2D Nanofiber Membranes to 3D Hierarchical Assemblies with Structural and Compositional Gradients Regulates Cell Behavior (Open Access)

(2020) *Advanced Materials*, 32 (43), art. no. 2003754. Cited 10 times.
http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1521-4095
doi: 10.1002/adma.202003754

View at Publisher

75 Dos Santos, D.M., Correa, D.S., Medeiros, E.S., Oliveira, J.E., Mattoso, L.H.C.

Advances in Functional Polymer Nanofibers: From Spinning Fabrication Techniques to Recent Biomedical Applications

(2020) *ACS applied materials & interfaces*, 12 (41), pp. 45673-45701. Cited 38 times.
doi: 10.1021/acsami.0c12410

View at Publisher

76 Unnithan, A.R., Barakat, N.A.M., Tirupathi Pichiah, P.B., Gnanasekaran, G., Nirmala, R., Cha, Y.-S., Jung, C.-H., (...), Kim, H.Y.

Wound-dressing materials with antibacterial activity from electrospun polyurethane-dextran nanofiber mats containing ciprofloxacin HCl

(2012) *Carbohydrate Polymers*, 90 (4), pp. 1786-1793. Cited 316 times.
doi: 10.1016/j.carbpol.2012.07.071

View at Publisher

77 Cruz-Maya, I., Guarino, V., Alvarez, M.A.

Protein based devices for oral tissue repair and regeneration (Open Access)

(2018) *AIMS Materials Science*, 5 (2), pp. 156-170. Cited 8 times.
http://www.aimspress.com/fileOther/PDF/Materials/matersci-05-02-156.pdf
doi: 10.3934/matersci.2018.2.156

View at Publisher

78 Memic, A., Abudula, T., Mohammed, H.S., Joshi Navare, K., Colombani, T., Bencherif, S.A.

Latest Progress in Electrospun Nanofibers for Wound Healing Applications

(2019) *ACS Applied Bio Materials*, 2 (3), pp. 952-969. Cited 105 times.
pubs.acs.org/journal/aabmcb
doi: 10.1021/acsabm.8b00637

View at Publisher

79 Krishnani, K.K., Chen, W., Mulchandani, A.

Bactericidal activity of elastin-like polypeptide biopolymer with polyhistidine domain and silver

(2014) *Colloids and Surfaces B: Biointerfaces*, 119, pp. 66-70. Cited 6 times.
www.elsevier.com/locate/colsurfb
doi: 10.1016/j.colsurfb.2014.03.018

View at Publisher

80 Mele, E.

Electrospinning of natural polymers for advanced wound care: Towards responsive and adaptive dressings (Open Access)

(2016) *Journal of Materials Chemistry B*, 4 (28), pp. 4801-4812. Cited 103 times.
http://pubs.rsc.org/en/journals/journalissues/tb
doi: 10.1039/c6tb00804f

View at Publisher

Khodir, W.K.W.A.; Department of Chemistry, Kulliyyah of Science, International Islamic University Malaysia Kuantan Campus, Bandar Indera Mahkota, Kuantan, Malaysia; email:wkhartini@iium.edu.my
Guarino, V.; Institute of Polymers, Composites and Biomaterials, National Research Council of Italy, Mostra d'Oltremare Pad.20, V.le J.F.Kennedy 54, Naples, Italy; email:vincenzo.guarino@cnr.it