NANOTEKNOLOJİNİN
TIP VE MÜHENDİSLİK UYGULAMALARI

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Nanoteknolojinin Tıp ve Mühendislik Uygulamaları

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ÖNSÖZ

Nanoteknoloji ilk olarak 1959'da fizikçi Richard Feynman'ın atomik ve moleküler düzeyde nesnelerin tasarımına yönelik önerileri ile ortaya çıkan bir kavram olmuştur. Nanoteknoloji kavramı tek başına bir bilimsel disiplin olarak değerlendirilmeyip temel bilimlerin (fizik, kimya, biyoloji) yanı sıra mühendislik ve malzeme bilimi alanındaki geleneksel konuların çeşitli yeni teknolojiler geliştirmek amacıyla kolektif olarak birbirine bağlanması sonucu ortaya çıkan disiplinler arası bir alandır.

İnsanoğlu varoluşundan beri hastalıkların teşhisi, tedavisi ve yaşam konforlarını azaltan unsurları ortadan kaldırmak ya da azaltmak için çeşitli yöntemler ve çareler aramaktadır. Yapılan çalışmalar tıpta ve mühendislikte nanoteknoloji uygulamalarının teşhis ve tedavi başta olmak üzere birçok alanda önemli derecede başarılı olabileceğini göstermektedir.

Radyolojik görüntülemede doku kontrastını artırmak için nanoteknoloji kullanılmakta ve tanıda önemli katkılar sağlamaktadır. Nanopartiküllerle yapılan incelemelerde kontrast etkisi oluşturan ajanın boyutlarının küçük olması hedef organ değerlendirmede ve tümör anjiogenezisinin belirlenmesinde oldukça kolaylıklar sağlamaktadır.

Hastalık teşhisi ve tedavisini tek bir nanoilaç formülasyonunda birleştiren nanoteranostik yöntemler önemli bir nanoteknolojik uygulamadır. Bu yöntemler farmakokinetik değerlendirme, belirli bir formülasyonun biyo-dağılımı, hedef bölgede birikimi ve ilaç salınımının non-invazif olarak gösterilmesi gibi ilaç dağıtım araştırmalarında kullanılmaktadır.

Nanopartiküller, üstün özellikleri nedeni ile biyolojik uygulamalarda yeni tekniklerin sağlanması ve temel biyolojik araştırmalarda da umut vaat etmekte ve biyolojik uygulamalarda hücre düzeyinde biyolojik süreç görüntülemesi ve analit tespiti gibi amaçlarla kullanılabilmektedir.

Nanopartiküllerin yüksek yüzey alanı, ilaç yükleme kapasitesi, ilaç taşıma yeteneği ve serbest bırakma özelliği sayesinde, ilaçların etkisi artırılabilir. Belirli hücre, doku veya organa yönelik etki, istenilen doz profili sağlanarak tedavi etkinliği optimize edilebilir, sistemik yan etkiler azaltılabilir, emilim ve etkinlik artırılabilir. Üretim maliyeti, onay süreci ve zorluklarına rağmen, nanopartiküller ilaç salım sistemlerinde önemli faydalar sağlamaktadır.

Son yıllarda nanoteknolojideki gelişmeler ışığında nanoyapıların mikroorganizmalarla etkileşimine bağlı olarak teşhis ve tedavi uygulamalarında avantajlar sağlamıştır. Güncel uygulamalarda nanopartikül tabanlı; antijen tespiti, PCR, immünofluoresans, elektrokimyasal sensörler, antikor ve protein tanı testleri, lateral flow testleri, yüzey kaplama ve mikrofluidik cihazlar, spektroskopik uygulamalar yaygın olarak kullanılmaktadır.

Hastalıkların teşhisinde kan, idrar ve doku gibi hastalık biyobelirteçlerinin düşük konsantrasyon ve eser miktarlarının kantitatif ve kalitatif analizleri, moleküllerin izlenmesi ve güvenilir bir şekilde saptanması için hızlı, doğru, hassas, ucuz, taşınabilir-giyilebilir ve kullanımı kolay ekipmanların geliştirilmesine ihtiyaç vardır. Bu bağlamda nanoteknoloji tabanlı geliştirilen Yüzey Zenginleştirilmiş Raman Spektroskopisi (YZRS) tekniği ve YZRS aktif alt taşları gelecek vadeden bir yaklaşım olarak görülmektedir.

Bu kitapta nanoteknolojide kullanılan malzemelerin sentez ve karakterizasyon metotları, sentezlenen nano ölçekli malzemelerin tıbbi biyokimyada tanı testlerinde kullanılması, tıbbi radyolojide görüntüleme kontrast maddesi olarak kullanılması, teranostik ve terapötik özellikleri, hücre ve moleküler biyolojik uygulamaları, ilaç salım sistemlerinde kullanılması, tıbbi mikrobiyolojik uygulamaları ve YZRS uygulamalarında metal nano parçacıkların rolü hakkında bilgiler sunulmuştur. Bu kitabın amacı nanoteknolojinin tıp ve mühendislik alanında temel araştırma ve uygulama çalışmaları yapan araştırmacılarımıza kapsamlı bir bilgi sağlamak ve onları bu alanda yenilikçi çalışmalar yapmaya teşvik etmektir. Araştırma çalışmaları ve yoğun emekleriyle bu amaca katkı sağlayan alanında uzman çok değerli yazarlarımıza gönülden teşekkür ediyoruz.

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BÖLÜM 1

Nanomalzemelerin Temel Özellikleri, Sentezi ve Karakterizasyon Teknikleri

Mehmet Salih NAS[1]

GİRİŞ

Nano terimi ilk olarak Yunanca cüce kelimesinden türetilmiştir ve anormal derecede kısa insan olarak da tanımlanmaktadır. Aynı zamanda ölçü ve zaman birimleri için bir ön ek olarak kullanılır ve bu birimlerin milyarda birine eşdeğer anlamına gelir. Dolayısıyla bir nanometre, metrenin milyarda birine karşılık gelen bir uzunluk birimidir. Nanometre bazlı malzemeler 1-100 nm boyut aralığına sahip örnekler olarak kabul edilir. Genel olarak, bir nanomalzeme, elde edilen malzemenin özelliklerinin boyutuyla veya elde edilen işleme süreçleriyle ilgili bir boyutla karakterize edilir. Bu durumda, gelişigüzel veya iyi organize edilmiş bir süreçle elde edilen bir malzemenin karakteristik özellikleri nanoyapılı malzemeler olarak kabul edilir. Nano ölçekli malzemeler, düşük erime noktası, kristal yapı, elektrik iletkenliği, manyetik ve optik özellikler, sensör hassasiyeti, oksidasyon ve aşınma direnci gibi yığın malzemelerden belirgin şekilde farklı özellikler sergiledikleri için uzun süredir bilim ve teknoloji alanında yaygın olarak kullanılmaktadır. Doğada çeşitli nanomalzemeler bulunabilmekte, genellikle farklı amaçlar için kullanılmak üzere belirli özellikleri içerecek şekilde farklı işlem yöntemleriyle laboratuvarda sentezlenmektedir. Üretilen nanomalzemelerin karakteristik boyutları belirli bir seviyeye ulaştığında malzemenin davranışı farklılaşmaktadır. Örneğin 5 nm'nin altındaki platin, altın ve paladyum nanoparçacıkları düşük sıcaklık

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1.4.6. Atomik Kuvvet Mikroskopisi (AFM)

Atomik Kuvvet Mikroskobu (AFM), nano ölçekteki numuneleri incelemek için çok yönlü ve güçlü bir mikroskopi teknolojisidir. AFM sadece üç boyutlu yüzey görüntülerine değil, aynı zamanda diferansiyel yüzey ölçümlerine de izin verir. Atomik kuvvet mikroskobu, angstrom ölçeğinde çözünürlük-yükseklik verileri ve atomik çözünürlük görüntüleri sağladığı için son derece kullanışlı bir araçtır. AFM, numune yüzeyini incelemek için atomik boyutlara kadar keskinleştirilmiş bir iğne ucu (0,2-10 nm) kullanır. Atomik kuvvet mikroskobu üç farklı teknikle kullanılabilir. Bunlar, iğnenin yüzeye temas ettirilerek uygulandığı temas yöntemi, iğnenin yüzeye temas etmediği temassız yöntem ve iğnenin yüzeye vurularak uygulandığı dokunma yöntemidir. Bir lazer ışını kullanılarak, yüzeye doğru veya yüzeyden uzağa doğru çubuk sapmaları tespit edilir. Lazer ışını çubuk benzeri malzemeden yansıtılır. Çubuk hareket ederse, yansıyan ışının açısı değişecektir. Bu değişiklikleri tespit etmek için konuma duyarlı bir foto diyot kullanılır. Lazer ışınının bu sapmaları, nano ölçekli yüzey girintilerini ve çıkıntılarını kaydetmek için kullanılır. Bahsedilen mikro yöntemle üretilen katalizörleri değerlendirmek için Atomik Kuvvet Mikroskobu (AFM) aparatı kullanılmıştır (Burhan vd., 2023).

Kaynaklar

Abd Ellah, N. H., & Abouelmagd, S. A. (2017). Tümör ilacı dağıtımı için polimerik nanopartiküllerin yüzey işlevselleştirilmesi: yaklaşımlar ve zorluklar. Expert Opinion on Drug Delivery, 14(2), 201-214. https://doi.org/10.1080/17425247.2016.1213238

Acquesta, A., & Monetta, T. (2021). Titanyumda Eklemeli Olarak Üretilen Parçaların Elektropolisajı: Son Teknoloji. Advanced Engineering Materials, 23(12). https://doi.org/10.1002/ADEM.202100545

Ahmed, K., Mehboob, N., Zaman, A., Ali, A., Mushtaq, M., Ahmad, D., Ahmed, N., Sultana, F., Bashir, K., Amami, M., Althubeiti, K., & Tirth, V. (2022). Elektronik cihaz uygulamaları için çinko oksit (ZnO) nanopartiküllerinin yapısal, optik ve elektriksel özellikleri üzerine Cu2+ katkısının geliştirilmesi. Journal of Luminescence, 250, 119112. https://doi.org/10.1016/J.JLUMIN.2022.119112

Al Baroot, A., Haladu, S. A., Magami, S. M., Akhtar, S., Drmosh, Q. A., Elsayed, K. A., & Manda, A. A. (2023). Çevre dostu darbeli lazer ablasyon tekniği ile sentezlenen Ag/TiO2/SiO2 nanokompozitinin fotokatalitik performansı. Journal of Physics and Chemistry of Solids, 180, 111489. https://doi.org/10.1016/J.JPCS.2023.111489

Ali, S., Khan, I., Khan, S. A., Sohail, M., Ahmed, R., Rehman, A. ur, Ansari, M. S., & Morsy, M. A. (2017). Metanol oksidasyon reaksiyonu için karbon nanotüpler üzerinde desteklenen Ni@Pt çekirdek-kabuk nanopartiküllerinin elektrokatalitik performansı. Journal of Electroanalytical Chemistry, 795, 17-25. https://doi.org/10.1016/J.JELECHEM.2017.04.040

Bhaduri, S. B. (1993). The Physics and Chemistry of Sol-Gel Processing edited by CJ Brinker and GW Scherer Academic Press, Inc., San Diego, CA 908 pages, hard cover, 1990.

Bumajdad, A., Zaki, M. I., Eastoe, J., & Pasupulety, L. (2004). Yüksek yüzey alanına ve yüksek sıcaklık kararlılığına sahip CeO2 tozlarının mikroemülsiyon bazlı sentezi. Langmuir, 20(25), 11223–11233.

Burhan, H., Arıkan, K., Alma, M. H., Nas, M. S., Karimi-Maleh, H., Şen, F., Karimi, F., & Vasseghian, Y. (2023). Doğrudan metanol yakıt hücreleri için anot katalizörleri olarak nano mimari kullanan yüksek verimli karbon hibrit destekli katalizörler. International Journal of Hydrogen Energy, 48(17), 6657-6665. https://doi.org/10.1016/J.IJHYDENE.2021.12.141

Cao, Y. W. C., Jin, R., & Mirkin, C. A. (2002). DNA ve RNA tespiti için Raman spektroskopik parmak izlerine sahip nanoparçacıklar. Science, 297(5586), 1536–1540. https://doi.org/10.1126/SCIENCE.297.5586.1536/SUPPL_FILE/CAO.SUP.PDF

Choi, S. U. S., Li, S., & Eastman, J. A. (1999). Oksit nanopartikülleri içeren akışkanların termal iletkenliğinin ölçülmesi. Journal of Heat Transfer, 121(2), 280-289. https://doi.org/10.1115/1.2825978

Demirkan, B., Bozkurt, S., Şavk, A., Cellat, K., Gülbağca, F., Nas, M. S., Alma, M. H., & Sen, F. (2019). Askorbik Asit, Dopamin ve Ürik Asitin Elektrokimyasal Tayini için Bimetalik Platin-Kobalt Alaşımlı Nanopartiküller ve İndirgenmiş Grafen Oksit Kompozitleri. Scientific Reports, 9(1). https://doi.org/10.1038/S41598-019-48802-0

Dong, D., Guo, H., Li, G., Yan, L., Zhang, X., & Song, W. (2017). Termoelektrik hücreler için içi boş karbon küre-grafen polilitik aerojellerin birleştirilmesi. Nano Energy, 39, 470-477. https://doi.org/10.1016/J.NANOEN.2017.07.029

Dreaden, E. C., Alkilany, A. M., Huang, X., Murphy, C. J., & El-Sayed, M. A. (2012). Altın çağ: biyotıp için altın nanopartiküller. Chemical Society Reviews, 41(7), 2740-2779.

Esa, Y. A. M., & Sapawe, N. (2020). Doğal bitki özleri aracılığıyla yeşil kimya ile sentezlenen çinko metal nanopartiküller üzerine kısa bir inceleme. Günümüzde Malzemeler: Proceedings, 31, 386-393. https://doi.org/10.1016/J.MATPR.2020.07.184

Fagerlund, G. (1973). BET yöntemi ile özgül yüzeyin belirlenmesi. Matériaux et Constructions, 6(3), 239-245. https://doi.org/10.1007/BF02479039/METRICS

Faivre, D., & Bennet, M. (2016). Manyetik nanopartiküller sıraya giriyor. Nature 2016 535:7611, 535(7611), 235-236. https://doi.org/10.1038/535235a

Fan, L., Zhu, M., Lee, X., Zhang, R., Wang, K., Wei, J., Zhong, M., Wu, D., & Zhu, H. (2013). Kimyasal Buhar Biriktirme ile Grafen Kuantum Noktalarının Doğrudan Sentezi. Particle & Particle Systems Characterization, 30(9), 764-769. https://doi.org/10.1002/PPSC.201300125

Fu, Y., Wang, G., Ming, X., Liu, X., Hou, B., Mei, T., Li, J., Wang, J., & Wang, X. (2018). Hızlı ve verimli güneş buharı üretimi için bir güneş emici olarak oksijen plazması ile işlenmiş grafen aerojel. Carbon, 130, 250-256. https://doi.org/10.1016/J.CARBON.2017.12.124

Ghorbani-Vaghei, R., Veisi, H., Aliani, M. H., Mohammadi, P., & Karmakar, B. (2021). Suda 4-nitrofenolün indirgenmesi için etkili bir manyetik nanokatalizör olarak altın nanopartiküllerin immobilizasyonuna yönelik aljinat modifiye manyetik nanopartiküller. Journal of Molecular Liquids, 327, 114868. https://doi.org/10.1016/J.MOLLIQ.2020.114868

Guo, X., Cheng, S., Cai, W., Zhang, Y., & Zhang, X. ao. (2021). Karbon bazlı termal arayüz malzemeleri üzerine bir inceleme: Mekanizma, termal ölçümler ve termal özellikler. Materials & Design, 209, 109936. https://doi.org/10.1016/J.MATDES.2021.109936

Indiarto, R., Putri, L., Indriana, A., Andoyo, R., Subroto, - Edy, & Nurhadi, - Bambang. (2022). Aşağıdan yukarıya nanopartikül sentezi: teknikler, polifenol bazlı çekirdek malzemeler ve özellikleri üzerine bir inceleme. 248, 1-24. https://doi.org/10.1007/s00217-021-03867-y

Ivashchenko, O., Peplińska, B., Gapiński, J., Flak, D., Jarek, M., Załęski, K., Nowaczyk, G., Pietralik, Z., & Jurga, S. (2018). Hidrokolloidlerde gümüş ve ultra küçük demir oksit nanopartikülleri: manyetik alan ve sıcaklığın kendi kendine organizasyon üzerindeki etkisi. Scientific RePORtS |, 8, 4041. https://doi.org/10.1038/s41598-018-22426-2

Karimi, F., Akin, M., Bayat, R., Bekmezci, M., Darabi, R., Aghapour, E., & Sen, F. (2023). Yakıt Pilleri İçin Metanol, 2-Propanol ve Gliserol Alkollerinin Elektro-Oksidasyonu için Yüksek Elektrokimyasal Performansa Sahip Yarı Altıgen Pt@PdS2-MWCNT katalizörünün Uygulanması. Molecular Catalysis, 536.

Katouzian, I., Faridi Esfanjani, A., Jafari, S. M., & Akhavan, S. (2017). Gıda biyoaktif bileşenleri için yeni nesil lipid nano taşıyıcıların formülasyonu ve uygulaması. Trends in Food Science & Technology, 68, 14-25. https://doi.org/10.1016/J.TIFS.2017.07.017

Khan, M. S., Saengon, P., Alganad, A. M. N., Chongcharoen, D., & Farrukh, M. (2020). Tüketicinin yeşil davranışı: Çevresel sürdürülebilirliğe yönelik bir yaklaşım. Sustainable Development, 28(5), 1168-1180. https://doi.org/10.1002/SD.2066

Kokturk, M., Yıldırım, S., Nas, M. S., Ozhan, G., Atamanalp, M., Bolat, I., Calimli, M. H., & Alak, G. (2022). Yeşil Sentez Nanopartikülün (RP-Ag/ACNPs) Zebra Balığında Oksidatif Stres Tepkisinin Araştırılması. Biological Trace Element Research, 200(6), 2897-2907.

Li, C., Shao, Z., Pang, M., Williams, C. T., & Liang, C. (2012). Fenilasetilen hidrojenasyonu için karbon nanotüp destekli Pt katalizörleri: oksijen içeren yüzey gruplarının Pt dağılımı ve katalitik performans üzerindeki etkileri. Catalysis Today, 186(1), 69-75. https://doi.org/10.1016/J.CATTOD.2011.09.005

Li, H., He, X., Liu, Y., Huang, H., Lian, S., Lee, S. T., & Kang, Z. (2011). Mükemmel fotolüminesan özelliklere sahip suda çözünür karbon nanoparçacıkların tek adımlı ultrasonik sentezi. Carbon, 49(2), 605-609. https://doi.org/10.1016/J.CARBON.2010.10.004

Liu, Y., Zhang, X., Deng, J., & Liu, Y. (2021). Sülfonamidlerin bozunması için etkili fenton benzeri katalizör olarak bilyalı öğütme stratejisiyle sentezlenen yeni bir CNTs-Fe3O4. Chemosphere, 277, 130305. https://doi.org/10.1016/J.CHEMOSPHERE.2021.130305

Lu, A. H., Salabas, E. L., & Schüth, F. (2007). Manyetik Nanopartiküller: Sentez, Koruma, İşlevselleştirme ve Uygulama. Angewandte Chemie International Edition, 46(8), 1222-1244. https://doi.org/10.1002/ANIE.200602866

Mansha, M., Khan, I., Ullah, N., & Qurashi, A. (2017). Karbazol içeren konjuge polimerlerin sentezi, karakterizasyonu ve görünür ışık güdümlü fotoelektrokimyasal hidrojen evrim reaksiyonu. International Journal of Hydrogen Energy, 42(16), 10952-10961. https://doi.org/10.1016/J.IJHYDENE.2017.02.053

Manzoor, M. F., Ahmad, E., Ullah, M., Rana, A. M., Malik, A. S., Farooq, M., Ahmad, I., Hasnain, M., Shah, Z. A., Khan, W. Q., & Mehtab, U. (2019). Bakır katkısının otomatik yanma ile sentezlenen ZnO nanokompozitlerin yapısal, elektriksel ve optik özellikleri üzerindeki etkisi. Acta Physica Polonica A, 135(3), 458-466. https://doi.org/10.12693/APHYSPOLA.135.458

Mishra, V., Bansal, K. K., Verma, A., Yadav, N., Thakur, S., Sudhakar, K., & Rosenholm, J. M. (2018). Katı Lipid Nanopartiküller: Gelişen Kolloidal Nano İlaç Dağıtım Sistemleri. Pharmaceutics, 10(4). https://doi.org/10.3390/PHARMACEUTICS10040191

Modekwe, H. U., Mamo, M., Moothi, K., & Daramola, M. O. (2021). Kimyasal buhar biriktirme yöntemiyle atık plastiklerin (polipropilen) karbon nanotüplere (CNT'ler) katalitik dönüşümü için bimetalik NiMo/MgO katalizörünün sentezi. Günümüzde Malzemeler: Proceedings, 38, 549-552. https://doi.org/10.1016/J.MATPR.2020.02.398

Moezzi, A., McDonagh, A. M., & Cortie, M. B. (2012). Çinko oksit partikülleri: Sentez, özellikler ve uygulamalar. Kimya Mühendisliği Dergisi, 185-186, 1-22. https://doi.org/10.1016/J.CEJ.2012.01.076

Monge, M., Fornaguera, C., Quero, C., Dols-Perez, A., Calderó, G., Grijalvo, S., García-Celma, M. J., Rodríguez-Abreu, C., & Solans, C. (2020). Nano-emülsiyon şablonlama ile hazırlanan fonksiyonelleştirilmiş PLGA nanopartikülleri, kan-beyin bariyerinden taşınmada rol oynayan proteinlerle seçici olarak etkileşime girer. European Journal of Pharmaceutics and Biopharmaceutics, 156, 155-164. https://doi.org/10.1016/J.EJPB.2020.09.003

Moodley, J. S., Krishna, S. B. N., Pillay, K., Sershen, & Govender, P. (2018). Moringa oleifera yaprak özlerinden gümüş nanopartiküllerin yeşil sentezi ve antimikrobiyal potansiyeli. Doğa Bilimlerinde Gelişmeler: Nanobilim ve Nanoteknoloji, 9(1), 015011. https://doi.org/10.1088/2043-6254/AAABB2

Moustafa, E. B., & Taha, M. A. (2020). Mekanik alaşımlama yöntemiyle yüksek mukavemetli grafen takviyeli Cu bazlı nanokompozitlerin hazırlanması: mikroyapısal, mekanik ve elektriksel özellikler. 126, 220. https://doi.org/10.1007/s00339-020-3412-0

Nas, M. S. (2021). Ultrasonik ışınlama altında metilen mavisinin degradasyonu için adsorpsiyon-sonokatalitik kombine yeni katalizör olarak AgFe2O4/MWCNT nanopartikülleri. Journal of Environmental Chemical Engineering, 9(3), 105207. https://doi.org/10.1016/J.JECE.2021.105207

Nas, M. S., Calimli, M. H., Burhan, H., Yılmaz, M., Mustafov, S. D., & Sen, F. (2019). Ultrasonik proses sistemleri kullanılarak sucul ortamlarda metilen mavisi giderimi için Pt-Co@GO nano-adsorbentin sentezi, karakterizasyonu, kinetiği ve adsorpsiyon özellikleri. Moleküler Sıvılar Dergisi, 296. https://doi.org/10.1016/J.MOLLIQ.2019.112100

Ngoy, J. M., Wagner, N., Riboldi, L., & Bolland, O. (2014). Poliaspartamid Yüzey Aktif Madde ile Çok Duvarlı Karbon Nanotüpler Kullanarak CO2 Yakalama Teknolojisi. Energy Procedia, 63, 2230-2248. https://doi.org/10.1016/J.EGYPRO.2014.11.242

Nguyen, V., Yan, L., Xu, H., & Yue, M. (2018). Ratiometrik sıcaklık algılama için çok emisyonlu karbon nanodotların tek adımda sentezi. Applied Surface Science, 427, 1118-1123. https://doi.org/10.1016/J.APSUSC.2017.08.133

Pal, K., Navin, K., & Kurchania, R. (2020). Toz metalurjisi yöntemiyle hazırlanan Al-ZrO2 metal matris nanokompozitlerin yapısal ve mekanik davranışlarının incelenmesi. Günümüzde Malzemeler: Proceedings, 26, 2714-2719. https://doi.org/10.1016/J.MATPR.2020.02.570

Parveen, S., Gupta, D. B., Dass, S., Kumar, A., Pandey, A., Chakraborty, S., & Chakraborty, N. (2016). Nohut ferritini CaFer1 oksidatif stres tepkisine katılır ve büyüme ve gelişmeyi destekler. Scientific Reports, 6. https://doi.org/10.1038/srep31218

Pramanik, S., Chatterjee, S., Kumar, G. S., & Devi, P. S. (2018). Baz çifti seçici DNA bağlanması ve tanınması için yumurta kabuğu türevi karbon noktalar. Fiziksel Kimya, Kimyasal Fizik - PCCP, 20(31), 20476-20488. https://doi.org/10.1039/C8CP02872A

Qi, K., Selvaraj, R., Al Fahdi, T., Al-Kindy, S., Kim, Y., Tai, C.-W., & Sillanpää, M. (2015). Hiyerarşik α-MnS mikroküreler: Solvotermal sentez ve büyüme mekanizması. https://doi.org/10.1016/j.matlet.2015.12.044

Rafiee, Z., & Jafari, S. M. (2018). Gıda Endüstrisi için Lipid Nanotaşıyıcıların Uygulanması. 1–43. https://doi.org/10.1007/978-3-319-54528-8_93-1

Rosowska, J., Kaszewski, J., Witkowski, B., Wachnicki, Kuryliszyn-Kudelska, I., & Godlewski, M. (2020). Mikrodalga hidrotermal yöntemle hazırlanan ZnO nanopartiküllerin özellikleri üzerinde demir içeriğinin etkisi. Optical Materials, 109. https://doi.org/10.1016/J.OPTMAT.2020.110089

Saeed, K., & Khan, I. (2016). Instrumentation Science & Technology Tek duvarlı karbon nanotüp/naylon 6, 6 nanokompozitlerin hazırlanması ve karakterizasyonu. https://doi.org/10.1080/10739149.2015.1127256

Şen, F., Demirbaş, Ö., Çalımlı, M. H., Aygün, A., Alma, M. H., & Nas, M. S. (2018). Polimer kompozit filmler kullanılarak sulu çözeltiden boya giderimi. Uygulamalı Su Bilimi, 8(7). https://doi.org/10.1007/S13201-018-0856-X

Shankar, S. S., Rai, A., Ahmad, A., & Sastry, M. (2004). Neem (Azadirachta indica) yaprak suyu kullanılarak Au, Ag ve bimetalik Au çekirdek-Ag kabuk nanopartiküllerinin hızlı sentezi. Journal of Colloid and Interface Science, 275(2), 496-502. https://doi.org/10.1016/J.JCIS.2004.03.003

Si, S., Li, W., Zhao, X., Han, M., Yue, Y., Wu, W., Guo, S., Zhang, X., Dai, Z., Wang, X., Xiao, X., & Jiang, C. (2017). Tek Katmanlı Grafen Ekleyerek Tungsten Nanofilmin Termal Taşınımında Önemli Radyasyon Toleransı ve Orta Derecede Azalma. Advanced Materials (Deerfield Beach, Fla.), 29(3). https://doi.org/10.1002/ADMA.201604623

Sigmund, W., Yuh, J., Park, H., Maneeratana, V., Pyrgiotakis, G., Daga, A., Taylor, J., & Nino, J. C. (2006). Seramik Elyaf Sistemlerinin Elektrospinninginde İşleme ve Yapı İlişkileri. Journal of the American Ceramic Society, 89(2), 395-407. https://doi.org/10.1111/J.1551-2916.2005.00807.X

Srivastava, R. (2012). Nanomalzemelerin Sentezi ve Karakterizasyon Teknikleri Makale içinde. International Journal of Green Nanotechnology. https://doi.org/10.1080/19430892.2012.654738

Sun, Y. P., Zhou, B., Lin, Y., Wang, W., Fernando, K. A. S., Pathak, P., Meziani, M. J., Harruff, B. A., Wang, X., Wang, H., Luo, P. G., Yang, H., Kose, M. E., Chen, B., Veca, L. M., & Xie, S. Y. (2006). Parlak ve renkli fotolüminesans için kuantum boyutlu karbon noktaları. Journal of the American Chemical Society, 128(24), 7756-7757. https://doi.org/10.1021/JA062677D

Suvarnaphaet, P., Tiwary, C. S., Wetcharungsri, J., Porntheeraphat, S., Hoonsawat, R., Ajayan, P. M., Tang, I.-M., & Asanithi, P. (2016). Limonatadan mavi fotolüminesan karbon nanodotlar. https://doi.org/10.1016/j.msec.2016.07.075

Thomas, R., Sanders, S., Doust, J., Beller, E., & Glasziou, P. (2015). Dikkat Eksikliği/Hiperaktivite Bozukluğunun Yaygınlığı: Sistematik Bir İnceleme ve Meta-analiz. Pediatrics, 135(4), e994-e1001. https://doi.org/10.1542/PEDS.2014-3482

Ur Rashid, H., Yu, K., Naveed Umar, M., Naveed Anjum, M., Khan, K., Ahmad, N., & Tariq Jan, M. (2015). KİMYASAL BUHAR BİRİKTİRME (CVD) SÜRECİNDE KATALİZÖRÜN ROLÜ: BİR İNCELEME. Rev. Adv. Mater. Sci, 40, 235-248.

Vangelie, E., Campos, R., Luiz De Oliveira, J., Morais Gonçalves Da Silva, C., Pascoli, M., Pasquoto, T., Lima, R., Abhilash, P. C., & Fernandes Fraceto, L. (2015). Tarımsal Uygulamalarda Karbendazim ve Tebukonazolün Sürekli Salınımı için Polimerik ve Katı Lipid Nanopartiküller. Scientific RepoRts |, 5, 13809. https://doi.org/10.1038/srep13809

Wang, J. C., Neogi, P., & Forciniti, D. (2006). Yüzey aktif madde kaplı nanoparçacıkların tek boyutlu kendi kendine birleşmesi üzerine. Journal of Chemical Physics, 125(19). https://doi.org/10.1063/1.2375091/566384

Xie, Y., Han, M., Wang, R., Zobeiri, H., Deng, X., Zhang, P., & Wang, X. (2019). Ultraviyoleden Uzak Kızılötesine Ultrasensitif Algılama için Grafen Aerojel Tabanlı Bolometre. ACS Nano, 13(5), 5385-5396.

Xing, T., Sunarso, J., Yang, W., Yin, Y., Glushenkov, A. M., Li, L. H., Howlett, P. C., & Chen, Y. (2013). Bilyalı öğütme: azot katkılı karbon nanopartiküllerin sentezi için yeşil bir mekanokimyasal yaklaşım. Nanoscale, 5(17), 7970-7976. https://doi.org/10.1039/C3NR02328A

Yang, J., Zhang, E., Li, X., Zhang, Y., Qu, J., & Yu, Z. Z. (2016). Termal enerji depolama için yüksek termal iletkenliğe ve iyi şekil kararlılığına sahip selüloz/grafen aerojel destekli faz değişim kompozitleri. Carbon, 98, 50-57. https://doi.org/10.1016/J.CARBON.2015.10.082

Yang, X., Liang, Y., Cheng, Y., Song, W., Wang, X., Wang, Z., & Qiu, J. (2014). Emülsiyon damlacıklarının ara yüzeylerine monte edilmiş karbon nanotüp destekli Ru katalizörleri üzerinde vanilinin hidrodeoksijenasyonu. Catalysis Communications, 47, 28-31. https://doi.org/10.1016/J.CATCOM.2013.12.027

Yehia, H. M., Abu-Oqail, A., Elmaghraby, M. A., & Elkady, O. A. (2020). Akımsız biriktirme ve toz metalurjisi tekniği ile (Cu/MoS2)/grafen nanokompozitin mikroyapı, sertlik ve tribolоji özellikleri. Https://Doi.Org/10.1177/0021998320916528, 54(23), 3435–3446. https://doi.org/10.1177/0021998320916528

Yıldız, A., Yeşilbaş, Ö. F., Nas, M. S., Calimli, M. H., Bayat, R., & Şen, F. (2023). Metilen mavisinin sonokatalitik bozunması için Pluronic F127 destekli sol-jel prosesi kullanılarak TiO2/f-MWCNT katalizörünün in situ hazırlanması. Environmental Research, 231, 115972. https://doi.org/10.1016/J.ENVRES.2023.115972

Zawadzki, M., & Wrzyszcz, J. (2000). Yüksek yüzey alanına sahip nano gözenekli çinko alüminatın hidrotermal sentezi. Materials Research Bulletin, 35(1), 109-114. https://doi.org/10.1016/S0025-5408(00)00185-9

Zeng, F. L., Sun, Y., Zhou, Y., & Li, Q. K. (2011). PVDF ve POSS nanokompozitlerinin elastik özelliklerini araştırmak için bir moleküler dinamik simülasyon çalışması. Malzeme Bilimi ve Mühendisliğinde Modelleme ve Simülasyon, 19(2), 025005. https://doi.org/10.1088/0965-0393/19/2/025005

Zeng, L., Li, X., Fan, S., Li, J., Mu, J., Qin, M., Wang, L., Gan, G., Tadé, M., & Liu, S. (2019). Güçlendirilmiş elektrik çıkışı ve mükemmel katalitik performansa sahip yüksek kaliteli karbon noktalarının biyoelektrokimyasal sentezi. Nanoscale, 11(10), 4428-4437. https://doi.org/10.1039/C8NR10510C

Zhang, L., Liu, X., Zhang, M., Yuan, H., Zhang, L., & Lu, J. (2019). Kataliz ve adsorpsiyon için çift fonksiyonlu Fe3O4@C-MoO2-Ni kompozitlerinin kolay yapımı. Applied Surface Science, 494, 783-794. https://doi.org/10.1016/J.APSUSC.2019.07.249

Zhang, M., Jiang, S., Han, F., Li, M., Wang, N., & Liu, L. (2021). Termal yönetim ve yağ emme özelliklerine sahip anizotropik selüloz nanofiber / kitosan aerojel. Carbohydrate Polymers, 264. https://doi.org/10.1016/J.CARBPOL.2021.118033

Zhang, Y., Li, J., & Che, S. (2018). ELEKTROKİMYA BİLİMİ Seçici Lazer Eritme ile Üretilen Ti-6Al-4V Alaşımının Elektropolisaj Mekanizması. Int. J. Electrochem. Sci, 13, 4792-4807. https://doi.org/10.20964/2018.0

BÖLÜM 2

Nanopartiküllerin Tanısal Tıbbi Biyokimyada Kullanımı

Fatma GÜR[1]

GİRİŞ

Nanopartikül tabanlı tasarlanan aygıtlar ve moleküler düzeyde etkinlik gösteren nano-yapılar biyolojik insan sistemlerinin kapsamlı gözetimini, kontrolünü, oluşturulmasını, onarımını ve savunmasını içeren metodolojilere katkı sağlamaktadır (Haleem ve ark., 2023). Bu kitap bölümünde, öncelikle nanoteknolojinin tıp alanındaki uygulamalarına genel bakış yaptıktan sonra farklı nanopartikül türlerini ve bunların tıbbi biyokimya alanında hastalıkların teşhisi amacıyla uygulamalarını yeni bulgu ve keşiflere özel vurgu yaparak inceledik. Nanopartiküller çeşitli teşhis tekniklerinin duyarlılığını, özgüllüğünü ve etkinliğini artırmak, biyobelirteçlerin ve hastalıkla ilgili moleküllerin daha yüksek doğrulukla tespit edilmesini sağlamak için avantaj sağlar ve tanısal tıbbi biyokimyada geniş bir uygulama alanına sahiptir. Bu bölümde tanısal tıbbi biyokimyada nanopartiküllerin önemli uygulamalarından moleküler teşhis, bağışıklık sistemi hastalıkları (immünoanalizler), bakım noktası testi, manyetik rezonans görüntüleme (MRI), mikro-akışkanlar ve çip üzerinde laboratuvar cihazları ile ilgili bilgiler verilmiştir. Nanoteknolojinin tıbbi biyokimyada tanı amacıyla kullanım uygulamaları sadece laboratuvarlarda yapılan testlerden ve tüketiciye ulaşması için sağlık kuruluşları tarafından onaylanması ile kalmayıp NPs'lerin hazırlanması ve uygulanması ile ilgili hem fayda hem de güvenliğin sağlanması ve biyolojik sistemlerle kullanılabilecek

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2.8. Sonuç ve Öneriler

Nanoteknoloji benzersiz nanodiagnostik potansiyeli nedeniyle biyosensör ve biyogörüntüleme alanında özel ilgi görmektedir. Bu NPs'ler elektrokimya, lüminesans, hedef etiketleme, SPR tabanlı biyosensörler gibi çeşitli stratejilerde uygulama alanı bulmuştur. Bu NPs'ler ayrıca hassasiyet ve çok yönlülükte eşzamanlı artışla birlikte sinerjistik koşulları teşvik etmek için farklı montaj yapılarında birleştirilebilir. NPs tabanlı yaklaşımların çoğu uygulaması, hedef olarak sentetik oligonükleotidler, mikroorganizmalar ve/veya virüsler ve iyi karakterize edilmiş protein biyobelirteçleri kullanılarak daha basit koşullarda gösterilmiştir. Bunlar kavramsallaştırmayla ilgili olsa da, klinik tarama stratejilerinin ciddi türlerinden uzaktır. Mevcut uygulamalar iyileştirildikten sonra, geliştirilen platformlar kavram kanıtından klinik ortama kolayca çevrilebilir ve bu da düşük verimli genotipleme yaklaşımlarından, geniş genom ve proteom karakterizasyonu için orta ila yüksek verimli tarama ve çoğullama yapabilen daha sağlam platformlara giden yolu açabilir. Nanoteknolojinin bu alanda kullanılması, laboratuvarlarda yapılan keşiflerden ve tüketiciler tarafından kullanılmak üzere sağlık kuruluşları ve otoriteler tarafından onaylanmaktan çok daha fazlasıdır. NPs'lerin hazırlanması ve uygulanması ile ilgili olarak uluslararası standartların ve terminolojinin oluşturulması ve sürdürülmesi, toksisite testi, risk değerlendirmesi ve hafifletilmesinin yanı sıra hem fayda hem de güvenliğin sağlanmasında halkın katılımı için küresel koordinasyona ihtiyaç duyulmaktadır. Bu, daha sonra biyolojik sistemlerle kullanılabilecek nano ölçekli öğeler ve ürünler için uluslararası kabul görmüş somut olarak standartlaştırılmış karakterizasyon protokollerini mümkün kılacaktır. Küresel koordinasyon aynı zamanda onaylanmış, mevcut, ayrıntılı ve köklü yönergelere ve spesifikasyonlara sıkı uyumun izlenmesini de sağlayacaktır. Nanoteknolojinin ve özellikle nanodiagnostiğin geleceği açısından özellikle DNA sekanslama sonuçlarına bağlı etik kaygılara gereken özen gösterilerek ve uluslararası standartların oluşturulmasında küresel bir yönelimle, sağlık hizmeti sunumunun bu alanındaki olanaklar hızla artmaya devam edecektir.

Kaynaklar

Alexander, T., Greco, R., & Snowden, J. A. (2021). Hematopoietic stem cell transplantation for autoimmune disease. *Annual Review of Medicine*, *72*, 215-228.

Ayoubi, M., Naserzadeh, P., Hashemi, M. T., Reza Rostami, M., Tamjid, E., Tavakoli, M. M., & Simchi, A. (2017). Biochemical mechanisms of dose-dependent cytotoxicity and ROS-mediated apoptosis induced by lead sulfide/graphene oxide quantum dots for potential bioimaging applications. *Scientific reports*, *7*(1), 12896.

Bai, Y.-H., Zhang, H., Xu, J.-J., & Chen, H.-Y. (2008). Relationship between Nanostructure and Electrochemical/Biosensing Properties of MnO2 Nanomaterials for H2O2/Choline. *The Journal of Physical Chemistry C*, *112*(48), 18984-18990. https://doi.org/10.1021/jp805497y

Baptista, P. V., Doria, G., Quaresma, P., Cavadas, M., Neves, C. S., Gomes, I., Eaton, P., Pereira, E., & Franco, R. (2011). Chapter 11 - Nanoparticles in Molecular Diagnostics. In A. Villaverde (Ed.), *Progress in Molecular Biology and Translational Science* (Vol. 104, pp. 427-488). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-416020-0.00011-5

Barick, K., Singh, S., Bahadur, D., Lawande, M. A., Patkar, D. P., & Hassan, P. (2014). Carboxyl decorated Fe3O4 nanoparticles for MRI diagnosis and localized hyperthermia. *Journal of colloid and interface science*, *418*, 120-125.

Boschi, F., & De Sanctis, F. (2017). Overview of the optical properties of fluorescent nanoparticles for optical imaging. *Eur J Histochem*, *61*(3), 2830. https://doi.org/10.4081/ejh.2017.2830

Broza, Y. Y., Har-Shai, L., Jeries, R., Cancilla, J. C., Glass-Marmor, L., Lejbkowicz, I., Torrecilla, J. S., Yao, X., Feng, X., & Narita, A. (2017). Exhaled breath markers for nonimaging and noninvasive measures for detection of multiple sclerosis. *ACS Chemical Neuroscience*, *8*(11), 2402-2413.

Castillo-León, J. (2014). Microfluidics and lab-on-a-chip devices: history and challenges. In *Lab-on-a-Chip Devices and Micro-Total Analysis Systems: A Practical Guide* (pp. 1-15). Springer.

De La Escosura-Muñiz, A., & Merkoçi, A. (2010). Electrochemical detection of proteins using nanoparticles: Applications to diagnostics [Review]. *Expert Opinion on Medical Diagnostics*, *4*(1), 21-37. https://doi.org/10.1517/17530050903386661

Dumas, A., & Couvreur, P. (2015). Palladium: a future key player in the nanomedical field? *Chemical Science*, *6*(4), 2153-2157.

Evans, E., Gabriel, E. F. M., Benavidez, T. E., Coltro, W. K. T., & Garcia, C. D. (2014). Modification of microfluidic paper-based devices with silica nanoparticles. *Analyst*, *139*(21), 5560-5567.

Fan, J., Yin, J.-J., Ning, B., Wu, X., Hu, Y., Ferrari, M., Anderson, G. J., Wei, J., Zhao, Y., & Nie, G. (2011). Direct evidence for catalase and peroxidase activities of ferritin–platinum nanoparticles. *Biomaterials*, *32*(6), 1611-1618. https://doi.org/https://doi.org/10.1016/j.biomaterials.2010.11.004

Fernandes, A. C., Duarte, C. M., Cardoso, F. A., Bexiga, R., Cardoso, S., & Freitas, P. P. (2014). Lab-on-chip cytometry based on magnetoresistive sensors for bacteria detection in milk. *Sensors*, *14*(8), 15496-15524.

Gaglia, J. L., Guimaraes, A. R., Harisinghani, M., Turvey, S. E., Jackson, R., Benoist, C., Mathis, D., & Weissleder, R. (2011). Noninvasive imaging of pancreatic islet inflammation in type 1A diabetes patients. *The Journal of clinical investigation*, *121*(1), 442-445.

Gautam, A., Guleria, P., & Kumar, V. (2020). Platinum nanoparticles: Synthesis strategies and applications. *Nanoarchitectonics*, 70-86.

Ghazanfari, M. R., Kashefi, M., Shams, S. F., & Jaafari, M. R. (2016). Perspective of Fe 3 O 4 nanoparticles role in biomedical applications. *Biochemistry research international*, *2016*.

Gorjikhah, F., Davaran, S., Salehi, R., Bakhtiari, M., Hasanzadeh, A., Panahi, Y., Emamverdy, M., & Akbarzadeh, A. (2016). Improving "lab-on-a-chip" techniques using biomedical nanotechnology: a review. *Artificial cells, nanomedicine, and biotechnology*, *44*(7), 1609-1614.

Haleem, A., Javaid, M., Singh, R. P., Rab, S., & Suman, R. (2023). Applications of Nanotechnology in Medical field. *Global Health Journal*.

He, R., Li, L., Zhang, T., Ding, X., Xing, Y., Zhu, S., Gu, Z., & Hu, H. (2023). Recent advances of nanotechnology application in autoimmune diseases – A bibliometric analysis. *Nano Today*, *48*, 101694. https://doi.org/https://doi.org/10.1016/j.nantod.2022.101694

Hu, M. Y., Li, Z. Z., Guo, C. P., Wang, M. H., He, L. H., & Zhang, Z. H. (2019). Hollow core-shell nanostructured MnO/FeO

embedded within amorphous carbon nanocomposite as sensitive bioplatform for detecting protein tyrosine kinase-7. *Applied Surface Science*, *489*, 13-24. https://doi.org/10.1016/j.apsusc.2019.05.146

Hu, X., Saran, A., Hou, S., Wen, T., Ji, Y., Liu, W., Zhang, H., & Wu, X. (2014). Rod-shaped Au@PtCu nanostructures with enhanced peroxidase-like activity and their ELISA application. *Chinese science bulletin*, *59*, 2588-2596.

Huang, S. H., & Juang, R. S. (2011). Biochemical and biomedical applications of multifunctional magnetic nanoparticles: a review. *Journal of Nanoparticle Research*, *13*(10), 4411-4430. https://doi.org/10.1007/s11051-011-0551-4

Jackson, T. C., Patani, B. O., & Ekpa, D. E. (2017). Nanotechnology in diagnosis: a review. *Advances in Nanoparticles*, *6*(03), 93-102.

Jafari, S., Derakhshankhah, H., Alaei, L., Fattahi, A., Varnamkhasti, B. S., & Saboury, A. A. (2019). Mesoporous silica nanoparticles for therapeutic/diagnostic applications. *Biomedicine & Pharmacotherapy*, *109*, 1100-1111. https://doi.org/https://doi.org/10.1016/j.biopha.2018.10.167

Jafari, S., Mahyad, B., Hashemzadeh, H., Janfaza, S., Gholikhani, T., & Tayebi, L. (2020). Biomedical Applications of TiO2 Nanostructures: Recent Advances. *International Journal of Nanomedicine*, *15*(null), 3447-3470. https://doi.org/10.2147/IJN.S249441

Jain, K. K. (2003). Nanodiagnostics: application of nanotechnology in molecular diagnostics. *Expert review of molecular diagnostics*, *3*(2), 153-161.

Jain, K. K. (2005). Nanotechnology in clinical laboratory diagnostics. *Clinica Chimica Acta*, *358*(1), 37-54. https://doi.org/https://doi.org/10.1016/j.cccn.2005.03.014

Jiang, C., Wang, G., Hein, R., Liu, N., Luo, X., & Davis, J. J. (2020). Antifouling strategies for selective in vitro and in vivo sensing. *Chemical reviews*, *120*(8), 3852-3889.

Jiang, W., Wang, Y., Wargo, J. A., Lang, F. F., & Kim, B. Y. (2021). Considerations for designing preclinical cancer immune nanomedicine studies. *Nature nanotechnology*, *16*(1), 6-15.

Jouyandeh, M., Sajadi, S. M., Seidi, F., Habibzadeh, S., Munir, M. T., Abida, O., Ahmadi, S., Kowalkowska-Zedler, D., Rabiee, N., Rabiee, M., Heidari, G., Hassanpour, M., Nazarzadeh Zare, E., & Saeb, M. R. (2022). Metal nanoparticles-assisted early diagnosis of diseases. *OpenNano*, *8*, 100104. https://doi.org/https://doi.org/10.1016/j.onano.2022.100104

Ju, Y., Zhang, H., Yu, J., Tong, S., Tian, N., Wang, Z., Wang, X., Su, X., Chu, X., & Lin, J. (2017). Monodisperse Au–Fe2C Janus nanoparticles: an attractive multifunctional material for triple-modal imaging-guided tumor photothermal therapy. *ACS nano*, *11*(9), 9239-9248.

Kawasaki, H., Yamamoto, H., Fujimori, H., Arakawa, R., Inada, M., & Iwasaki, Y. (2010). Surfactant-free solution synthesis of fluorescent platinum subnanoclusters. *Chemical communications*, *46*(21), 3759-3761.

Lai, C. Y., Trewyn, B. G., Jeftinija, D. M., Jeftinija, K., Xu, S., Jeftinija, S., & Lin, V. S. Y. (2003). A mesoporous silica nanosphere-based carrier system with chemically removable CdS nanoparticle caps for stimuli-responsive controlled release of neurotransmitters and drug molecules. *Journal of the American Chemical Society*, *125*(15), 4451-4459. https://doi.org/10.1021/ja028650l

Lee, J. H., Jun, Y. w., Yeon, S. I., Shin, J. S., & Cheon, J. (2006). Dual-mode nanoparticle probes for high-performance magnetic resonance and fluorescence imaging of neuroblastoma. *Angewandte Chemie International Edition*, *45*(48), 8160-8162.

Lin, J., Song, T., Liu, Z., Yang, D., Xiang, R., Hua, W., & Wan, H. (2022). Effects of biodegradable biomedical porous MnO2 nanoparticles on blood components and functions. *Colloids and Surfaces B: Biointerfaces*, *217*, 112667. https://doi.org/https://doi.org/10.1016/j.colsurfb.2022.112667

Liu, J., Feng, L., & Wu, Y. (2021). Enzymatically synthesised MnO 2 nanoparticles for efficient near-infrared photothermal therapy and dual-responsive magnetic resonance imaging. *Nanoscale*, *13*(25), 11093-11103.

Liu, J., Liu, Z. Y., Pang, Y., & Zhou, H. F. (2022). The interaction between nanoparticles and immune system: application in the treatment of inflammatory diseases. *Journal of Nanobiotechnology*, *20*(1). https://doi.org/ARTN 127
10.1186/s12951-022-01343-7

Lu, Z.-R., Ye, F., & Vaidya, A. (2007). Polymer platforms for drug delivery and biomedical imaging. *Journal of Controlled Release*, *122*(3), 269-277.

Luo, S., Ma, C., Zhu, M. Q., Ju, W. N., Yang, Y., & Wang, X. (2020). Application of Iron Oxide Nanoparticles in the Diagnosis and Treatment of Neurodegenerative Diseases With Emphasis on Alzheimer's Disease. *Frontiers in Cellular Neuroscience*, *14*. https://doi.org/ARTN 2110.3389/fncel.2020.00021

Luo, X., Morrin, A., Killard, A. J., & Smyth, M. R. (2006). Application of nanoparticles in electrochemical sensors and biosensors. *Electroanalysis: An International Journal Devoted to Fundamental and Practical Aspects of Electroanalysis*, *18*(4), 319-326.

Mangraviti, A., Tzeng, S. Y., Kozielski, K. L., Wang, Y., Jin, Y., Gullotti, D., Pedone, M., Buaron, N., Liu, A., & Wilson, D. R. (2015). Polymeric nanoparticles for nonviral gene therapy extend brain tumor survival in vivo. *ACS nano*, *9*(2), 1236-1249.

Mauk, M., Song, J., Bau, H. H., Gross, R., Bushman, F. D., Collman, R. G., & Liu, C. (2017). Miniaturized devices for point of care molecular detection of HIV. *Lab on a Chip*, *17*(3), 382-394.

Mazetyte-Stasinskiene, R., & Köhler, J. M. (2020). Sensor micro and nanoparticles for microfluidic application. *Applied Sciences*, *10*(23), 8353.

Mazzaracchio, V., Bagheri, N., Chiara, F., Fiore, L., Moscone, D., Roggero, S., & Arduini, F. (2023). A smart paper-based electrochemical sensor for reliable detection of iron ions in serum. *Analytical and Bioanalytical Chemistry*, *415*(6), 1149-1157.

Medina-Sánchez, M., Miserere, S., & Merkoçi, A. (2012). Nanomaterials and lab-on-a-chip technologies. Lab on a Chip,

Mirasoli, M., Guardigli, M., Michelini, E., & Roda, A. (2014). Recent advancements in chemical luminescence-based lab-on-chip and microfluidic platforms for bioanalysis. *Journal of pharmaceutical and biomedical analysis*, *87*, 36-52.

MubarakAli, D., Kim, H., Venkatesh, P. S., Kim, J. W., & Lee, S. Y. (2023). A Systemic Review on the Synthesis, Characterization, and Applications of Palladium Nanoparticles in Biomedicine. *Applied Biochemistry and Biotechnology*, *195*(6), 3699-3718. https://doi.org/10.1007/s12010-022-03840-9

Naseri, N., Janfaza, S., & Irani, R. (2015). Visible light switchable bR/TiO
nanostructured photoanodes for bio-inspired solar energy conversion. *Rsc Advances*, *5*(24), 18642-18646. https://doi.org/10.1039/c4ra16188b

Nodland, S. (2020). *İmmünomodülatör nedir ve bağışıklığın desteklenmesine nasıl yardımcı olur?* Green Family. Retrieved 17.12.2023 from https://greenfamily.com.tr/blog/immunomodulator-nedir-ve-bagisikligin-desteklenmesine-nasil-yardimci-olur

Palazzo, G., Facchini, L., & Mallardi, A. (2012). Colorimetric detection of sugars based on gold nanoparticle formation. *Sensors and Actuators B: Chemical*, *161*(1), 366-371.

Park, J., Shin, J. H., & Park, J. K. (2016). Pressed Paper-Based Dipstick for Detection of Foodborne Pathogens with Multistep Reactions [Article]. *Analytical Chemistry*, *88*(7), 3781-3788. https://doi.org/10.1021/acs.analchem.5b04743

Pashchenko, O., Shelby, T., Banerjee, T., & Santra, S. (2018). A comparison of optical, electrochemical, magnetic, and colorimetric point-of-care biosensors for infectious disease diagnosis. *ACS infectious diseases*, *4*(8), 1162-1178.

Polsky, R., Gill, R., Kaganovsky, L., & Willner, I. (2006). Nucleic Acid-Functionalized Pt Nanoparticles: Catalytic Labels for the Amplified Electrochemical Detection of Biomolecules. *Analytical Chemistry*, *78*(7), 2268-2271. https://doi.org/10.1021/ac0519864

Prakash, R., Pabbaraju, K., Wong, S., Wong, A., Tellier, R., & Kaler, K. (2013). Droplet microfluidic chip based nucleic acid amplification and real-time detection of influenza viruses. *Journal of The Electrochemical Society*, *161*(2), B3083.

Pu, Z., Zou, C., Wang, R., Lai, X., Yu, H., Xu, K., & Li, D. (2016). A continuous glucose monitoring device by graphene modified electrochemical sensor in microfluidic system. *Biomicrofluidics*, *10*(1).

Rajasundari, K., & Ilamurugu, K. (2011). Nanotechnology and its applications in medical diagnosis. *J. Basic. Appl. Chem*, *1*(2), 26-32.

Reich, D. (2015). In Vivo Characterization of Inflammation with Ferumoxytol, an Ultrasmall Superparamagnetic Iron Oxide Nanoparticle, on 7 Tesla Magnetic Resonance Imaging. *ClinicalTrials. gov Identifier: NCT02511028*.

Sechi, D., Greer, B., Johnson, J., & Hashemi, N. (2013). Three-dimensional paper-based microfluidic device for assays of protein and glucose in urine. *Analytical chemistry*, *85*(22), 10733-10737.

Sharonova, A., Loza, K., Surmeneva, M., Surmenev, R., Prymak, O., & Epple, M. (2016). Synthesis of positively and negatively charged silver nanoparticles and their deposition on the surface of titanium. IOP Conference Series: Materials Science and Engineering,

Sherin, S., Balachandran, S., & Abraham, A. (2020). Curcumin incorporated titanium dioxide nanoparticles as MRI contrasting agent for early diagnosis of atherosclerosis-rat model. *Veterinary and Animal Science*, *10*, 100090.

Sohal, N., Maity, B., Shetti, N. P., & Basu, S. (2021). Biosensors Based on MnO2 Nanostructures: A Review. *ACS Applied Nano Materials*, *4*(3), 2285-2302. https://doi.org/10.1021/acsanm.0c03380

Song, Y. J., Xia, X. F., Wu, X. F., Wang, P., & Qin, L. D. (2014). Integration of Platinum Nanoparticles with a Volumetric Bar-Chart Chip for Biomarker Assays. *Angewandte Chemie-International Edition*, *53*(46), 12451-12455. https://doi.org/10.1002/anie.201404349

Syedmoradi, L., Daneshpour, M., Alvandipour, M., Gomez, F. A., Hajghassem, H., & Omidfar, K. (2017). Point of care testing: The impact of nanotechnology. *Biosensors and Bioelectronics*, *87*, 373-387. https://doi.org/https://doi.org/10.1016/j.bios.2016.08.084

Tajik, S., Dourandish, Z., Zhang, K., Beitollahi, H., Van Le, Q., Jang, H. W., & Shokouhimehr, M. (2020). Carbon and graphene quantum dots: A review on syntheses, characterization, biological and sensing applications for neurotransmitter determination. *RSC advances*, *10*(26), 15406-15429.

Tan, P., Li, H., Wang, J., & Gopinath, S. C. (2021). Silver nanoparticle in biosensor and bioimaging: Clinical perspectives. *Biotechnology and Applied Biochemistry*, *68*(6), 1236-1242.

Tan, S., Erol, M., Attygalle, A., Du, H., & Sukhishvili, S. (2007). Synthesis of positively charged silver nanoparticles via photoreduction of AgNO3 in branched polyethyleneimine/HEPES solutions. *Langmuir*, *23*(19), 9836-9843.

Team, E. (2023). Introduction to lab-on-a-chip 2023: review, history and future. *Elveflow*.

Tekin, V., Aweda, T., Guldu, O. K., Muftuler, F. Z. B., Bartels, J., Lapi, S. E., & Unak, P. (2021). A novel anti-angiogenic radio/photo sensitizer for prostate cancer imaging and therapy: 89Zr-Pt@ TiO2-SPHINX, synthesis and in vitro evaluation. *Nuclear Medicine and Biology*, *94*, 20-31.

Tran, N., & Webster, T. J. (2010). Magnetic nanoparticles: biomedical applications and challenges. *Journal of Materials Chemistry*, *20*(40), 8760-8767.

Understandingnano. (2023). *Nanotechnology in Medical Diagnostics*. <p>UnderstandingNano: Website dedicated to providing clear and concise explanations of nanotechnology applications along with information on companies working in each area.</p>

Vaishampayan, V., Kapoor, A., & Gumfekar, S. P. (2023). Enhancement in the limit of detection of lab-on-chip microfluidic devices using functional nanomaterials. *The Canadian Journal of Chemical Engineering*.

Vallabani, N. V. S., & Singh, S. (2018). Recent advances and future prospects of iron oxide nanoparticles in biomedicine and diagnostics. *3 Biotech*, *8*(6). https://doi.org/ARTN 27910.1007/s13205-018-1286-z

Verma, N., & Kumar, N. (2019). Synthesis and Biomedical Applications of Copper Oxide Nanoparticles: An Expanding Horizon. *ACS Biomaterials Science & Engineering*, *5*(3), 1170-1188. https://doi.org/10.1021/acsbiomaterials.8b01092

Willner, I., & Willner, B. (2010). Biomolecule-Based Nanomaterials and Nanostructures. *Nano Letters*, *10*(10), 3805-3815. https://doi.org/10.1021/nl102083j

Wilson, R. H., Nadeau, K. P., Jaworski, F. B., Tromberg, B. J., & Durkin, A. J. (2015). Review of short-wave infrared spectroscopy and imaging methods for biological tissue characterization. *Journal of biomedical optics*, *20*(3), 030901-030901.

Wolfbeis, O. S. (2015). An overview of nanoparticles commonly used in fluorescent bioimaging. *Chemical Society Reviews*, *44*(14), 4743-4768.

Wu, H., Su, Y., Jiang, J., Liang, Y., & Zhang, C. (2020). Ultrasensitive electrochemiluminescence detection of p53 gene by a novel cloth-based microfluidic biosensor with luminol-gold nanoparticles and hybridization chain reaction amplification. *Journal of Luminescence*, *226*, 117485.

Wu, J. D., Dong, M. L., Rigatto, C., Liu, Y., & Lin, F. (2018). Lab-on-chip technology for chronic disease diagnosis. *Npj Digital Medicine*, *1*. https://doi.org/ARTN 7
10.1038/s41746-017-0014-0

Xiao, J., Liu, Y., Su, L., Zhao, D., Zhao, L., & Zhang, X. (2019). Microfluidic chip-based wearable colorimetric sensor for simple and facile detection of sweat glucose. *Analytical chemistry*, *91*(23), 14803-14807.

Xie, J., Chen, K., Huang, J., Lee, S., Wang, J., Gao, J., Li, X., & Chen, X. (2010). PET/NIRF/MRI triple functional iron oxide nanoparticles. *Biomaterials*, *31*(11), 3016-3022. https://doi.org/https://doi.org/10.1016/j.biomaterials.2010.01.010

Xu, H., Xia, A. Y., Wang, D. D., Zhang, Y. H., Deng, S. L., Lu, W. P., Luo, J., Zhong, Q., Zhang, F. L., Zhou, L., Zhang, W. Q., Wang, Y., Yang, C., Chang, K., Fu, W. L., Cui, J. H., Gan, M. Z., Luo, D., & Chen, M. (2020). An ultraportable and versatile point-of-care DNA testing platform. *Science Advances*, *6*(17). https://doi.org/ARTN eaaz744510.1126/sciadv.aaz7445

Yang, H., & Zhu, Y. (2006). Size dependence of SiO2 particles enhanced glucose biosensor. *Talanta*, *68*(3), 569-574.

Yang, S.-Y., Chiu, M.-J., Lin, C.-H., Horng, H.-E., Yang, C.-C., Chieh, J.-J., Chen, H.-H., & Liu, B.-H. (2016). Development of an ultra-high sensitive immunoassay with plasma biomarker for differentiating Parkinson disease dementia from Parkinson disease using antibody functionalized magnetic nanoparticles. *Journal of nanobiotechnology*, *14*, 1-8.

Yi, X., Wu, Y. X., Tan, G. X., Yu, P., Zhou, L., Zhou, Z. N., Chen, J. Q., Wang, Z. G., Pang, J. S., & Ning, C. Y. (2017). Palladium nanoparticles entrapped in a self-supporting nanoporous gold wire as sensitive dopamine biosensor. *Scientific Reports*, *7*. https://doi.org/ARTN 7941 10.1038/s41598-017-07909-y

Yu, H., Yu, J., Li, L., Zhang, Y., Xin, S., Ni, X., Sun, Y., & Song, K. (2021). Recent Progress of the Practical Applications of the Platinum Nanoparticle-Based Electrochemistry Biosensors. *Front Chem*, *9*, 677876. https://doi.org/10.3389/fchem.2021.677876

Zhou, W., Gao, X., Liu, D., & Chen, X. (2015). Gold nanoparticles for in vitro diagnostics. *Chemical reviews*, *115*(19), 10575-10636.

BÖLÜM 3

Nanopartiküllerin Tanısal Radyolojide Kullanım Alanları

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GİRİŞ

Tanısal radyolojide doku kontrastını arttırmanın temel yöntemlerinden bir tanesi kontrast madde kullanımıdır. Pozitif kontrast maddeler X ve gama ışınları (γ) ile yapılan görüntülemelerde yüksek dansiteli, manyetik rezonans incelemelerde T1 ağırlıklı görüntülerde yüksek sinyal intensiteli ve ultrasonografik görüntülemelerde ise yüksek ekojenitede görülür. Görüntüdeki parlaklık ilgili organın diğer anatomik yapılardan ayrı olarak incelenmesini kolaylaştırır. Nanopartiküllerle yapılan incelemelerde kontrast etkisi oluşturan ajanın boyutlarının küçük olması hedef organ değerlendirilmesinde ve tümör anjiogenezisinin belirlenmesinde çok kolaylıklar sağlar. Son yıllarda çok sayıda nanopartiküler kontrast ajan geliştirilmiş olup, nanopartiküllerle yapılan radyolojik incelemeler her geçen gün daha yaygın kullanılmaktadır. Bu bölümde yazarlar radyolojinin farklı görüntüleme alanlarında geliştirilen nanopartiküler kontrast ajanlardan, bunların etki mekanizmasından ve görüntülemeye olan katkılarından bahsedilecektir.

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Sonuç olarak nanopartikül kontrast ajanların geliştirilmesi son dekatta nispeten azalmakla birlikte devam etmekdir. X-ışını temelli görüntüleme yöntemlerinde kullanılan kontrast ajanların en önemli yan etkisi olan nefrotoksisite sebebiyle böbrekler için güvenli bir kontrast ajan ihtiyacı mevcuttur. Ayrıca güncel kontrast ajanların böbrekler aracılığıyla hızlıca temizlenmesi de görüntülenme süresini kısa olmasına neden olmaktadır. Molekül boyutu büyütülerek oluşturulacak nanopartikül kontrast ajanların uzun yarı ömürlü olmasının yanı sıra plasenta bariyerini de geçememesi de büyük avantaj olarak görülmektedir. Nanopartikül ajanların tedavi amacıyla kullanılabilecek şekilde modifiye edilebiliyor olması da konvansiyonel kontrast maddelere göre büyük avantaj sağlamaktadır. Bu bilgiler ışığında ilerleyen yıllarda toksik olmayan, biyolojik olarak parçalanabilen ve biyouyumlu nanopartikül kontrast ajanların kullanıma girebileceği açıktır.

Kaynaklar

Allphin AJ, Mowery YM, Lafata KJ, Clark DP, Bassil AM, Castillo R, et al. Photon counting CT and radiomic analysis enables differentiation of tumors based on lymphocyte burden. Tomography. 2022;8(2):740–53.

Amini SM, Rezayat SM, Dinarvand R, Kharrazi S, Jaafari MR. Gold cluster encapsulated liposomes: theranostic agent with stimulus triggered release capability. Med Oncol. 2023;40(5):126.

Anton N, Parlog A, Bou About G, Attia MF, Wattenhofer-Donzé M, Jacobs H, et al. Non-invasive quantitative imaging of hepatocellular carcinoma growth in mice by micro-CT using liver-targeted iodinated nano-emulsions. Sci Rep. 2017;7(1):13935.

Attia MF, Anton N, Chiper M, Akasov R, Anton H, Messaddeq N, et al. Biodistribution of X-ray iodinated contrast agent in nano-emulsions is controlled by the chemical nature of the oily core. ACS Nano. 2014;8(10):10537–50.

Avasthi A, Caro C, Pozo-Torres E, Leal MP, García-Martín ML. Magnetic nanoparticles as MRI contrast agents. Top Curr Chem. 2020;378(3):40.

Black KC, Akers WJ, Sudlow G, Xu B, Laforest R, Achilefu S. Dual-radiolabeled nanoparticle SPECT probes for bioimaging. Nanoscale. 2015;7(2):440-444.

Brede C, Labhasetwar V. Applications of nanoparticles in the detection and treatment of kidney diseases. Adv Chronic Kidney Dis. 2013;20(6):454–65.

Chakraborty A, Royce SG, Selomulya C, Plebanski M. A novel approach for non-ınvasive lung ımaging and targeting lung ımmune cells. Int J Mol Sci. 2020;21(5).

Choi JW, Moon W-J. Gadolinium deposition in the brain: current updates. Korean J Radiol. 2019;20(1):134–47.

Cole LE, Ross RD, Tilley JMR, Vargo-Gogola T, Roeder RK. Gold nanoparticles as contrast agents in x-ray imaging and computed tomography. Nanomedicine. 2015;10(2):321–41.

Duncan R, Izzo L. Dendrimer biocompatibility and toxicity. Adv Drug Deliv Rev. 2005;57(15):2215–37.

Edelman RR. The history of MR imaging as seen through the pages of radiology. Radiology. 2014;273(2 Suppl):S181-200.

Estelrich J, Sánchez-Martín MJ, Busquets MA. Nanoparticles in magnetic resonance imaging: from simple to dual contrast agents. Int J Nanomedicine. 2015;10:1727–41.

Fu Y, Nitecki DE, Maltby D, Simon GH, Berejnoi K, Raatschen H-J, et al. Dendritic iodinated contrast agents with PEG-cores for CT imaging: synthesis and preliminary characterization. Bioconjug Chem. 2006;17(4):1043–56.

Gulani V, Calamante F, Shellock FG, Kanal E, Reeder SB. Gadolinium deposition in the brain: summary of evidence and recommendations. Lancet Neurol. 2017;16(7):564–70.

Gupta AK, Gupta M. Synthesis and surface engineering of iron oxide nanoparticles for biomedical applications. Biomaterials. 2005;26(18):3995–4021.

Hainfeld JF, Slatkin DN, Focella TM, Smilowitz HM. Gold nanoparticles: a new X-ray contrast agent. Br J Radiol [Internet]. 2006;79(939):248–53.

Hamm B. Iron-oxide-enhanced MR lymphography: just a new toy or a breakthrough? European radiology. 2002;12:957–8.

Han X , Xu K , Taratula O , Farsad K . Applications of nanoparticles in biomedical imaging. Nanoscale. 2019;11(3):799-819.

Han X, Xu K, Taratula O, Farsad K. Applications of nanoparticles in biomedical imaging. Nanoscale. 2019;11(3):799–819.

He Z, Wan X, Schulz A, Bludau H, Dobrovolskaia MA, Stern ST, et al. A high capacity polymeric micelle of paclitaxel: Implication of high dose drug therapy to safety and in vivo anti-cancer activity. Biomaterials [Internet]. 2016;101:296–309.

Hsu JC, Naha PC, Lau KC, Chhour P, Hastings R, Moon BF, et al. An all-in-one nanoparticle (AION) contrast agent for breast cancer screening with DEM-CT-MRI-NIRF imaging. Nanoscale. 2018;10(36):17236–48.

Hsu JC, Nieves LM, Betzer O, Sadan T, Noël PB, Popovtzer R, et al. Nanoparticle contrast agents for X-ray imaging applications. Wiley Interdiscip Rev Nanomed Nanobiotechnol. 2020;12(6):e1642.

Hu Y, Wang Y, Jiang J, Han B, Zhang S, Li K, Ge S, Liu Y. Preparation and Characterization of Novel Perfluorooctyl Bromide Nanoparticle as Ultrasound Contrast Agent via Layer-by-Layer Self-Assembly for Folate-Receptor-Mediated Tumor Imaging. Biomed Res Int. 2016;2016:6381464.

Ji C, Zhao M, Wang C, Liu R, Zhu S, Dong X, et al. Biocompatible tantalum nanoparticles as radiosensitizers for enhancing therapy efficacy in primary tumor and metastatic sentinel lymph nodes. ACS Nano. 2022;16(6):9428–41.

Khan R. MRI Contrast agents: evolution of clinical practice and dose optimization. Top Magn Reson Imaging. 2016;25(4):157–61.

Kim D, Jeong YY, Jon S. A drug-loaded aptamer-gold nanoparticle bioconjugate for combined CT imaging and therapy of prostate cancer. ACS Nano. 2010;4(7):3689–96.

Kim GW, Kang C, Oh YB, Ko MH, Seo JH, Lee D. Ultrasonographic imaging and anti-inflammatory therapy of muscle and tendon injuries using polymer nanoparticles. Theranostics. 2017;7(9):2463-2476.

Kinch MS, Woodard PK. Analysis of FDA-approved imaging agents. Drug Discov Today [Internet]. 2017;22(7):1077–83.

Kweon S, Lee H-J, Hyung WJ, Suh J, Lim JS, Lim S-J. Liposomes coloaded with iopamidol/lipiodol as a RES-targeted contrast agent for computed tomography imaging. Pharm Res. 2010;27:1408–15.

Leong HS, Butler KS, Brinker CJ, Azzawi M, Conlan S, Dufés C, et al. On the issue of transparency and reproducibility in nanomedicine. Vol. 14, Nature nanotechnology. England; 2019. p. 629–35.

Leung K. Bismuth sulphide polyvinylpyrrolidone nanoparticles. In Bethesda (MD); 2004.

Lu C-H, Hsiao J-K. Diagnostic and therapeutic roles of iron oxide nanoparticles in biomedicine. Tzu chi Med J. 2023;35(1):11–7.
Lu J, Ma S, Sun J, Xia C, Liu C, Wang Z, et al. Manganese ferrite nanoparticle micellar nanocomposites as MRI contrast agent for liver imaging. Biomaterials. 2009;30(15):2919–28.
Maes RM, Lewin JS, Duerk JL, Misselwitz B, Kiewiet CJM, Wacker FK. A new type of susceptibility-artefact-based magnetic resonance angiography: intra-arterial injection of superparamagnetic iron oxide particles (SPIO) A Resovist® in combination with TrueFisp imaging: a feasibility study. Contrast Media Mol Imaging [Internet]. 2006;1(5):189–95.
Mathur M, Jones JR, Weinreb JC. gadolinium deposition and nephrogenic systemic fibrosis: a radiologist's primer. Radiogr a Rev Publ Radiol Soc North Am Inc. 2020;40(1):153–62.
Minhas AS, Oliver R. Magnetic Resonance Imaging Basics. Adv Exp Med Biol. 2022;1380:47–82.
Mohammadi M, Khademi S, Choghazrdi Y, Irajirad R, Keshtkar M, Montazerabadi A. Modified bismuth nanoparticles: a new targeted nanoprobe for computed tomography ımaging of cancer. Cell J. 2022;24(9):515–21.
Naha PC, Lau KC, Hsu JC, Hajfathalian M, Mian S, Chhour P, et al. Gold silver alloy nanoparticles (GSAN): an imaging probe for breast cancer screening with dual-energy mammography or computed tomography. Nanoscale. 2016;8(28):13740–54.
Na H Bin, Song IC, Hyeon T. Inorganic nanoparticles for MRI contrast agents. Adv Mater [Internet]. 2009;21(21):2133–48.
Nieves LM, Dong YC, Rosario-Berríos DN, Mossburg K, Hsu JC, Cramer GM, et al. Renally excretable silver telluride nanoparticles as contrast agents for X-ray imaging. ACS Appl Mater Interfaces. 2022;14(30):34354–64.
Nieves LM, Mossburg K, Hsu JC, Maidment ADA, Cormode DP. Silver chalcogenide nanoparticles: a review of their biomedical applications. Nanoscale. 2021;13(46):19306–23.
Owens TC, Anton N, Attia MF. CT and X-ray contrast agents: Current clinical challenges and the future of contrast. Acta Biomater [Internet]. 2023;171:19–36.
Pressly ED, Pierce RA, Connal LA, Hawker CJ, Liu Y. Nanoparticle PET/CT imaging of natriuretic peptide clearance receptor in prostate cancer. Bioconjug Chem. 2013;24(2):196-204.
Qiao Z, Shi X. Dendrimer-based molecular imaging contrast agents. Prog Polym Sci. 2015;44:1–27.
Ramalho J, Semelka RC, Ramalho M, Nunes RH, AlObaidy M, Castillo M. Gadolinium-based contrast agent accumulation and toxicity: an update. Am J Neuroradiol. 2016;37(7):1192–8.
Röhrl L. M.; Scharf, G.; Zeman, F.; Stroszczynski, C.; Schreyer, A. G. S. D. Informed consent in contrast-enhanced CT: understanding of risks and ıdentification of possible prognostic factors TT - patientenaufklärung bei kontrastmittelgestützter CT: risikoverständnis und ıdentifikation möglicher prognosefaktoren. Rofo [Internet]. 2015;187(11):973–9.
Salari Sedigh S, Gholipour A, Zandi M, Qubais Saeed B, Al-Naqeeb BZT, Abdullah Al-Tameemi NM, et al. The role of bismuth nanoparticles in the inhibition of bacterial infection. World J Microbiol Biotechnol. 2023;39(7):190.

Siddique S, Chow JCL. Application of Nanomaterials in Biomedical Imaging and Cancer Therapy. Vol. 10, Nanomaterials. 2020.

Thorek DLJ, Chen AK, Czupryna J, Tsourkas A. Superparamagnetic iron oxide nanoparticle probes for molecular imaging. Ann Biomed Eng. 2006;34(1):23–38.

Torchilin VP. PEG-based micelles as carriers of contrast agents for different imaging modalities. Adv Drug Deliv Rev [Internet]. 2002;54(2):235–52.

Ventola CL. Progress in nanomedicine: approved and ınvestigational nanodrugs. P T. 2017;42(12):742–55.

Wallyn J, Anton N, Mertz D, Begin-Colin S, Perton F, Serra CA, et al. Magnetite-and iodine-containing nanoemulsion as a dual modal contrast agent for X-ray/magnetic resonance imaging. ACS Appl Mater Interfaces. 2018;11(1):403–16.

Wallyn J, Anton N, Serra CA, Bouquey M, Collot M, Anton H, et al. A new formulation of poly (MAOTIB) nanoparticles as an efficient contrast agent for in vivo X-ray imaging. Acta Biomater. 2018;66:200–12.

Wang J, Barback CV, Ta CN, Weeks J, Gude N, Mattrey RF, Blair SL, Trogler WC, Lee H and Kummel AC. Extended lifetime in vivo pulse stimulated ultrasound imaging. IEEE Trans Med Imaging. 2018;37:222–229.

Wang X, Chen H, Zheng Y, Ma M, Chen Y, Zhang K, Zeng D, Shi J. Au-nanoparticle coated mesoporous silica nanocapsule-based multifunctional platform for ultrasound mediated imaging, cytoclasis and tumor ablation. Biomaterials. 2013;34(8):2057-68.

Wang Z, Qiao R, Tang N, Lu Z, Wang H, Zhang Z, et al. Active targeting theranostic iron oxide nanoparticles for MRI and magnetic resonance-guided focused ultrasound ablation of lung cancer. Biomaterials. 2017;127:25–35.

Wu Z, Dai L, Tang K, Ma Y, Song B, Zhang Y, et al. Advances in magnetic resonance imaging contrast agents for glioblastoma-targeting theranostics. Regen Biomater. 2021;8(6):rbab062.

Yang H, Zhao J, Li D, Cao Y, Li F, Ma J, et al. Application of silver nanotriangles as a novel contrast agent in tumor computed tomography imaging. Nanotechnology. 2021;32(49):495705.

Yang H, Zhuang Y, Sun Y, Dai A, Shi X, Wu D, et al. Targeted dual-contrast T1- and T2-weighted magnetic resonance imaging of tumors using multifunctional gadolinium-labeled superparamagnetic iron oxide nanoparticles. Biomaterials. 2011;32(20):4584–93.

Yoo D, Jung W, Son Y, Jon S. Glutathione-responsive gold nanoparticles as computed tomography contrast agents for hepatic diseases. ACS Appl Bio Mater. 2021;4(5):4486–94.

Yordanov AT, Lodder AL, Woller EK, Cloninger MJ, Patronas N, Milenic D, et al. Novel iodinated dendritic nanoparticles for computed tomography (CT) imaging. Nano Lett. 2002;2(6):595–9.

Zhou Y, Dai Z. New strategies in the design of nanomedicines to oppose uptake by the mononuclear phagocyte system and enhance cancer therapeutic efficacy. Chem Asian J. 2018;13(22):3333–40.

BÖLÜM 4

Nanopartiküllerin Teranostik ve Terapötik Özellikleri

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Giriş

Nanoteknolojinin birçok farklı uygulama alanı vardır. Bu uygulama alanlarının büyük bir kısmı sağlık alanında olup tıbbi girişim, tedavi ve teşhis aşamalarında uygulanan görüntüleme, akıllı ilaç uygulamaları ve erken teşhis için kullanılabilen tarama cihazları, ajanları ve uygulama metotlarını içermektedir. Nanotıp, nanoteknolojinin tıbbi uygulamalarını tanımlayan terimdir. Nanotıp terimi, hastalıkların önlenmesi, teşhisi, tedavisi, patofizyolojisinin anlaşılması ve hastaların yaşam kalitesinin iyileştirilmesi için nanometre boyuttaki araçların kullanımını kapsamaktadır (Choi ve ark., 2022; Miyazawa ve ark., 2021; Wang ve ark., 2021). Bilimsel araştırmalar ve uygulamalar kapsamında nanotıp alanında son yıllarda önemli gelişmeler kaydedilmiştir. Bu gelişmeler sonucunda bu alanda kullanılan birçok formülasyonun daha etkili, daha az toksik, teşhis ve tedavi girişimleri konusundaki yüksek potansiyelini ortaya konulmuştur. Nanoilaç formülasyonlarının geliştirilmesinde, multidisipliner araştırmalar ile hastalık teşhisi ve tedavisini tek bir nanoilaç formülasyonunda birleştirmeye yönelik çalışmalar gerçekleştirilmektedir. Bu özellikleri bir arada gösteren gelişmiş nanoilaç formülasyonları nanoteranostik olarak adlandırılmaktadır. Nanoteranostikleri kapsayan bu yöntemler nanoteranostik yöntemler olarak adlandırılmaktadır. Nanoteranostik yöntemler, farmakokinetik değerlendirme, belirli bir formülasyonun biyo-dağılımı, hedef bölgede birikimi ve ilaç salınımının non-invazif olarak

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tabanlı kemoterapötik uygulamaların kişiselleştirilmesi için yararlı olduğu düşünülmektedir (Thayath ve ark., 2021b).

Hastaların önceden seçimi aşamasında da nanoteranostikler kullanılarak non-invazif görüntüleme ile tümör hedefli ilaç dağıtımı birleştirerek kullanılabilmektedir. Hastaların nanoilaç formülasyonuyla tedavisi için önceden seçiminde ilk aşamada, yalnızca orta ve yüksek oranda tümör birikimi gösteren bireyler seçilmektedir. Düşük hedef bölge lokalizasyonu olan veya hiç birikim göstermeyen hastalar alternatif tedaviler için seçilmektedir. Hasta seçiminde ikinci aşamada non-invaziv görüntüleme kullanılarak terapötik etkinlik izlenebilmekte ve tümör hedefli nanokemoterapötik uygulamaya iyi yanıt veren hastalar tedavi için belirlenmektedir.

Teranostik yaklaşımlar diğer tanı ve tedavi yaklaşımlarına kıyasla daha çok emek gerektirmektedir fakat hem endüstriyel açıdan hem de klinik ve hasta açısından nanoilaçların kullanımını kapsayan erken faz klinik araştırmaların kolaylaştırılması ve teşviki için çok önemli olup yalnızca EPR aracılı yeterli tümör hedeflemesi gösteren hastaların uygulamaya ve etkinlik analizlerine dahil edilmesini sağlamaktadırlar. Hedef dışı lokalizasyonu çok yüksek olan hastaların uygulama dışında bırakılması için görüntüleme bilgilerinin birlikte kullanılması beklenmedik yan etkilerin insidansını ve yoğunluğunu azaltmaya yönelik yardımcı ajanlar olarak da nanoteranostikler kullanılmaktadır. Tüm bu bilgiler, nanoteranostiklerin ve ilaç hedefleme ile görüntüleme tekniğinin kombine edilmesinin kişisel tedavi uygulaması için potansiyelinin yüksek olduğunu göstermektedir.

Kaynaklar

Aboelzahab, A., Azad, A. M., Dolan, S., & Goel, V. (2012). Mitigation of Staphylococcus aureus-Mediated Surgical Site Infections with IR Photoactivated TiO2 coatings on Ti Implants. *Advanced Healthcare Materials*, *1*(3), 285-291.

Ahmad, E., Fatima, M. T., Hoque, M., Owais, M., & Saleemuddin, M. (2015). Fibrin matrices: The versatile therapeutic delivery systems. *International journal of biological macromolecules*, *81*, 121-136.

Alexander, J. W. (2009). History of the medical use of silver. *Surgical Infections*, *10*(3), 289-292.

Ali, E. S., Sharker, S. M., Islam, M. T., Khan, I. N., Shaw, S., Rahman, M. A., Uddin, S. J., Shill, M. C., Rehman, S., & Das, N. (2021). Targeting cancer cells with nanotherapeutics and nanodiagnostics: Current status and future perspectives. Seminars in Cancer Biology,

Ali, I., Alsehli, M., Scotti, L., Tullius Scotti, M., Tsai, S.-T., Yu, R.-S., Hsieh, M. F., & Chen, J.-C. (2020). Progress in polymeric nano-medicines for theranostic cancer treatment. *Polymers*, *12*(3), 598.

Alshehri, S., Imam, S. S., Rizwanullah, M., Akhter, S., Mahdi, W., Kazi, M., & Ahmad, J. (2020). Progress of cancer nanotechnology as diagnostics, therapeutics, and theranostics nanomedicine: preclinical promise and translational challenges. *Pharmaceutics*, *13*(1), 24.

Andronescu, E., & Grumezescu, A. M. (2017). *Nanostructures for drug delivery*. Elsevier.

Ansari, M. A., Khan, H. M., Khan, A. A., Sultan, A., & Azam, A. (2012). Synthesis and characterization of the antibacterial potential of ZnO nanoparticles against extended-spectrum β-lactamases-producing Escherichia coli and Klebsiella pneumoniae isolated from a tertiary care hospital of North India. *Applied microbiology biotechnology*, *94*, 467-477.

Armentano, I., Arciola, C. R., Fortunati, E., Ferrari, D., Mattioli, S., Amoroso, C. F., Rizzo, J., Kenny, J. M., Imbriani, M., & Visai, L. (2014). The interaction of bacteria with engineered nanostructured polymeric materials: a review. *The Scientific World Journal*, *2014*.

Au - Castaneda, R. T., Au - Khurana, A., Au - Khan, R., & Au - Daldrup-Link, H. E. (2011). Labeling Stem Cells with Ferumoxytol, an FDA-Approved Iron Oxide Nanoparticle. *JoVE*(57), e3482. https://doi.org/doi:10.3791/3482

Bagalkot, V., Zhang, L., Levy-Nissenbaum, E., Jon, S., Kantoff, P. W., Langer, R., & Farokhzad, O. C. (2007). Quantum Dot−Aptamer Conjugates for Synchronous Cancer Imaging, Therapy, and Sensing of Drug Delivery Based on Bi-Fluorescence Resonance Energy Transfer. *Nano Letters*, *7*(10), 3065-3070. https://doi.org/10.1021/nl071546n

Bernardi, A., Braganhol, E., Jäger, E., Figueiró, F., Edelweiss, M. I., Pohlmann, A. R., Guterres, S. S., & Battastini, A. M. (2009). Indomethacin-loaded nanocapsules treatment reduces in vivo glioblastoma growth in a rat glioma model. *Cancer letters*, *281*(1), 53-63.

Chatzimitakos, T. G., & Stalikas, C. D. (2016). Qualitative alterations of bacterial metabolome after exposure to metal nanoparticles with bactericidal properties: a comprehensive workflow based on 1H NMR, UHPLC-HRMS, and metabolic databases. *Journal of proteome research*, *15*(9), 3322-3330.

Chen, H.-Y., Deng, J., Wang, Y., Wu, C.-Q., Li, X., & Dai, H.-W. (2020). Hybrid cell membrane-coated nanoparticles: a multifunctional biomimetic platform for cancer diagnosis and therapy. *Acta biomaterialia*, *112*, 1-13.

Chen, J. L.-Y., Pan, C.-K., Lin, Y.-L., Tsai, C.-Y., Huang, Y.-S., Yang, W.-C., Hsu, F.-M., Kuo, S.-H., & Shieh, M.-J. (2021). Preclinical evaluation of PEGylated liposomal doxorubicin as an effective radiosensitizer in chemoradiotherapy for lung cancer. *Strahlentherapie und Onkologie*, *197*(12), 1131-1142.

Chen, X., Gambhir, S. S., & Cheon, J. (2011). Theranostic nanomedicine. In A. o. c. research (Ed.), (Vol. 44, pp. 841-841): ACS Publications.

Choi, K.-A., Kim, J. H., Ryu, K., & Kaushik, N. (2022). Current nanomedicine for targeted vascular disease treatment: trends and perspectives. *International Journal of Molecular Sciences*, *23*(20), 12397.

Chytil, P., Kostka, L., & Etrych, T. (2021). HPMA copolymer-based nanomedicines in controlled drug delivery. *Journal of Personalized Medicine*, *11*(2), 115.

Clack, K., Soda, N., Kasetsirikul, S., Mahmudunnabi, R. G., Nguyen, N. T., & Shiddiky, M. J. (2023). Toward Personalized Nanomedicine: The Critical Evaluation of Micro and Nanodevices for Cancer Biomarker Analysis in Liquid Biopsy. *Small*, *19*(15), 2205856.

d'Angelo, M., Castelli, V., Benedetti, E., Antonosante, A., Catanesi, M., Dominguez-Benot, R., Pitari, G., Ippoliti, R., & Cimini, A. (2019). Theranostic nanomedicine for malignant gliomas. *Frontiers in bioengineering biotechnology*, *7*, 325.

Della Valle, C., Visai, L., Santin, M., Cigada, A., Candiani, G., Pezzoli, D., Arciola, C. R., Imbriani, M., & Chiesa, R. (2012). A novel antibacterial modification treatment of titanium capable to improve osseointegration. *The International Journal of Artificial Organs*, *35*(10), 864-875.

Domoxoudis, S., Koukourakis, I. M., Giakzidis, A. G., & Koukourakis, M. I. (2019). Hypofractionated accelerated chemo-radiotherapy (Chemo-HypoAR) with cisplatin and liposomal doxorubicin for the treatment of patients with uterine sarcomas. *in vivo*, *33*(5), 1621-1624.

Du, M., Yang, Z., Lu, W., Wang, B., Wang, Q., Chen, Z., Chen, L., Han, S., Cai, T., & Cai, Y. (2020). Design and development of spirulina polysaccharide-loaded nanoemulsions with improved the antitumor effects of paclitaxel. *Journal of microencapsulation*, *37*(6), 403-412.

Duchêne, D., Ponchel, G., & Wouessidjewe, D. (1999). Cyclodextrins in targeting: application to nanoparticles. *Advanced Drug Delivery Reviews*, *36*(1), 29-40.

Duncan, R., & Gaspar, R. (2011). Nanomedicine (s) under the microscope. *Molecular pharmaceutics*, *8*(6), 2101-2141.

Elsabahy, M., & Wooley, K. L. (2012). Design of polymeric nanoparticles for biomedical delivery applications. *Chemical Society Reviews*, *41*(7), 2545-2561.

Foster, H. A., Ditta, I. B., Varghese, S., & Steele, A. (2011). Photocatalytic disinfection using titanium dioxide: spectrum and mechanism of antimicrobial activity. *Applied microbiology biotechnology*, *90*, 1847-1868.

Gao, W., Thamphiwatana, S., Angsantikul, P., & Zhang, L. (2014). Nanoparticle approaches against bacterial infections. *Wiley interdisciplinary reviews: nanomedicine nanobiotechnology*, *6*(6), 532-547.

Gorain, B., Choudhury, H., Nair, A. B., Dubey, S. K., & Kesharwani, P. (2020). Theranostic application of nanoemulsions in chemotherapy. *Drug discovery today*, *25*(7), 1174-1188.

Hari, S. K., Gauba, A., Shrivastava, N., Tripathi, R. M., Jain, S. K., & Pandey, A. K. (2023). Polymeric micelles and cancer therapy: An ingenious multimodal tumor-targeted drug delivery system. *Drug Delivery Translational Research*, *13*(1), 135-163.

Haroon, H. B., Hunter, A. C., Farhangrazi, Z. S., & Moghimi, S. M. (2022). A brief history of long circulating nanoparticles. *Advanced Drug Delivery Reviews*, *188*, 114396. https://doi.org/https://doi.org/10.1016/j.addr.2022.114396

Heister, E., Neves, V., Tîlmaciu, C., Lipert, K., Beltrán, V. S., Coley, H. M., Silva, S. R. P., & McFadden, J. (2009). Triple functionalisation of single-walled carbon nanotubes with doxorubicin, a monoclonal antibody, and a fluorescent marker for targeted cancer therapy. *Carbon*, *47*(9), 2152-2160. https://doi.org/https://doi.org/10.1016/j.carbon.2009.03.057

Hu, B., Boakye- Yiadom, K. O., Yu, W., Yuan, Z. W., Ho, W., Xu, X., & Zhang, X. Q. (2020). Nanomedicine approaches for advanced diagnosis and treatment of atherosclerosis and related ischemic diseases. *Advanced Healthcare Materials*, *9*(16), 2000336.

Huh, J., & Kwon, Y. J. (2011). "Nanoantibiotics": a new paradigm for treating infectious diseases using nanomaterials in the antibiotics resistant era. *Journal of Controlled Release*, *156*(2), 128-145.

Jaiswal, M., Dudhe, R., & Sharma, P. (2015). Nanoemulsion: an advanced mode of drug delivery system. *Biotech*, *5*, 123-127.

Jamieson, T., Bakhshi, R., Petrova, D., Pocock, R., Imani, M., & Seifalian, A. M. (2007). Biological applications of quantum dots. *Biomaterials*, *28*(31), 4717-4732. https://doi.org/https://doi.org/10.1016/j.biomaterials.2007.07.014

Jeon, J. Y., Ayyar, V. S., & Mitra, A. (2022). Pharmacokinetic and pharmacodynamic modeling of siRNA therapeutics–a minireview. *Pharmaceutical Research*, *39*(8), 1749-1759.

Johnsen, K. B., Bak, M., Melander, F., Thomsen, M. S., Burkhart, A., Kempen, P. J., Andresen, T. L., & Moos, T. (2019). Modulating the antibody density changes the uptake and transport at the blood-brain barrier of both transferrin receptor-targeted gold nanoparticles and liposomal cargo. *Journal of Controlled Release*, *295*, 237-249. https://doi.org/https://doi.org/10.1016/j.jconrel.2019.01.005

Jung, W. K., Koo, H. C., Kim, K. W., Shin, S., Kim, S. H., & Park, Y. H. (2008). Antibacterial activity and mechanism of action of the silver ion in Staphylococcus aureus and Escherichia coli. *Applied Environmental Microbiology*, *74*(7), 2171-2178.

Kamali, M., Persson, K. M., Costa, M. E., & Capela, I. (2019). Sustainability criteria for assessing nanotechnology applicability in industrial wastewater treatment: Current status and future outlook. *Environment international*, *125*, 261-276.

Khan, A. U., Khan, M., Cho, M. H., & Khan, M. M. (2020). Selected nanotechnologies and nanostructures for drug delivery, nanomedicine and cure. *Bioprocess biosystems engineering*, *43*, 1339-1357.

Kim, K. S., Youn, Y. S., & Bae, Y. H. (2019). Immune-triggered cancer treatment by intestinal lymphatic delivery of docetaxel-loaded nanoparticle. *Journal of Controlled Release*, *311*, 85-95.

Kong, X., Xu, J., Yang, X., Zhai, Y., Ji, J., & Zhai, G. (2022). Progress in tumour-targeted drug delivery based on cell-penetrating peptides. *Journal of Drug Targeting*, *30*(1), 46-60.

Kose, N., Çaylak, R., Pekşen, C., Kiremitçi, A., Burukoglu, D., Koparal, S., & Doğan, A. (2016). Silver ion doped ceramic nano-powder coated nails prevent infection in open fractures: in vivo study. *Injury*, *47*(2), 320-324.

Kreutzer, J., Schneider, M., Schlegel, U., Ewerbeck, V., & Breusch, S. (2005). Cemented total hip arthroplasty in Germany--an update. *Zeitschrift fur Orthopadie und ihre Grenzgebiete*, *143*(1), 48-55.

Krishnamoorthy, K., & Rajappan, M. (2012). Nanosponges: a novel class of drug delivery system--review. *Journal of Pharmacy Pharmaceutical Sciences: a Publication of the Canadian Society for Pharmaceutical Sciences, Societe Canadienne des Sciences Pharmaceutiques*, *15*(1), 103-111.

Kukowska-Latallo, J. F., Candido, K. A., Cao, Z., Nigavekar, S. S., Majoros, I. J., Thomas, T. P., Balogh, L. P., Khan, M. K., & Baker, J. R., Jr. (2005). Nanoparticle Targeting of Anticancer Drug Improves Therapeutic Response in Animal Model of Human Epithelial Cancer. *Cancer Research*, *65*(12), 5317-5324. https://doi.org/10.1158/0008-5472.CAN-04-3921 %J Cancer Research

Kumari, M., Giri, V. P., Pandey, S., Kumar, M., Katiyar, R., Nautiyal, C. S., Mishra, A., & physiology. (2019). An insight into the mechanism of antifungal activity of biogenic nanoparticles than their chemical counterparts. *Pesticide biochemistry*, *157*, 45-52.

Lammers, T., Kiessling, F., Hennink, W. E., & Storm, G. (2010). Nanotheranostics and image-guided drug delivery: current concepts and future directions. *Molecular pharmaceutics*, *7*(6), 1899-1912.

Lazzari, G., Vinciguerra, D., Balasso, A., Nicolas, V., Goudin, N., Garfa-Traore, M., Fehér, A., Dinnyes, A., Nicolas, J., & Couvreur, P. (2019). Light sheet fluorescence microscopy versus confocal microscopy: In quest of a suitable tool to assess drug and nanomedicine penetration into multicellular tumor spheroids. *European Journal of Pharmaceutics Biopharmaceutics*, *142*, 195-203.

Lee, D.-K., Kim, S. V., Limansubroto, A. N., Yen, A., Soundia, A., Wang, C.-Y., Shi, W., Hong, C., Tetradis, S., & Kim, Y. (2015). Nanodiamond–gutta percha composite biomaterials for root canal therapy. *ACS nano*, *9*(11), 11490-11501.

Legge, C. J., Colley, H. E., Lawson, M. A., & Rawlings, A. E. (2019). Targeted magnetic nanoparticle hyperthermia for the treatment of oral cancer. *48*(9), 803-809. https://doi.org/https://doi.org/10.1111/jop.12921

Lellouche, J., Friedman, A., Lellouche, J.-P., Gedanken, A., & Banin, E. (2012). Improved antibacterial and antibiofilm activity of magnesium fluoride nanoparticles obtained by water-based ultrasound chemistry. *Nanomedicine: Nanotechnology, Biology Medicine*, *8*(5), 702-711.

Lesniak, A., Salvati, A., Santos-Martinez, M. J., Radomski, M. W., Dawson, K. A., & Åberg, C. (2013). Nanoparticle adhesion to the cell membrane and its effect on nanoparticle uptake efficiency. *Journal of the American Chemical Society*, *135*(4), 1438-1444.

Leuba, K. D., Durmus, N. G., Taylor, E. N., & Webster, T. J. (2013). carboxylate functionalized superparamagnetic iron oxide nanoparticles (SPION) for the reduction of S. aureus growth post biofilm formation. *International journal of nanomedicine*, 731-736.

Li, C., Fu, R., Yu, C., Li, Z., Guan, H., Hu, D., Zhao, D., & Lu, L. (2013). Silver nanoparticle/chitosan oligosaccharide/poly (vinyl alcohol) nanofibers as wound dressings: a preclinical study. *International journal of nanomedicine*, 4131-4145.

Li, H., Chen, Q., Zhao, J., & Urmila, K. (2015). Enhancing the antimicrobial activity of natural extraction using the synthetic ultrasmall metal nanoparticles. *Scientific Reports*, *5*(1), 11033.

Li, Y., Zhang, W., Niu, J., & Chen, Y. (2012). Mechanism of photogenerated reactive oxygen species and correlation with the antibacterial properties of engineered metal-oxide nanoparticles. *ACS nano*, *6*(6), 5164-5173.

Lim, J., Kostiainen, M., Maly, J., Da Costa, V. C., Annunziata, O., Pavan, G. M., & Simanek, E. E. (2013). Synthesis of large dendrimers with the dimensions of small viruses. *Journal of the American Chemical Society*, *135*(12), 4660-4663.

Lin, J., Zhang, H., Chen, Z., & Zheng, Y. (2010). Penetration of lipid membranes by gold nanoparticles: insights into cellular uptake, cytotoxicity, and their relationship. *ACS nano*, *4*(9), 5421-5429.

Lo, S.-T., Kumar, A., Hsieh, J.-T., & Sun, X. (2013). Dendrimer nanoscaffolds for potential theranostics of prostate cancer with a focus on radiochemistry. *Molecular pharmaceutics*, *10*(3), 793-812.

Lu, B., Xiong, S.-B., Yang, H., Yin, X.-D., & Chao, R.-B. (2006). Solid lipid nanoparticles of mitoxantrone for local injection against breast cancer and its lymph node metastases. *European journal of pharmaceutical sciences*, *28*(1-2), 86-95.

Luan, B., Huynh, T., & Zhou, R. (2016). Complete wetting of graphene by biological lipids. *Nanoscale*, *8*(10), 5750-5754.

Ma, P., Dong, X., Swadley, C. L., Gupte, A., Leggas, M., Ledebur, H. C., & Mumper, R. J. (2009). Development of idarubicin and doxorubicin solid lipid nanoparticles to overcome Pgp-mediated multiple drug resistance in leukemia. *Journal of biomedical nanotechnology*, *5*(2), 151-161.

Mehata, A. K., Viswanadh, M. K., Priya, V., Vikas, & Muthu, M. S. (2020). Dendritic cell-targeted theranostic nanomedicine: advanced cancer nanotechnology for diagnosis and therapy. In (Vol. 15, pp. 947-949): Future Medicine.

Meng, J., Fan, J., Galiana, G., Branca, R. T., Clasen, P. L., Ma, S., Zhou, J., Leuschner, C., Kumar, C. S. S. R., Hormes, J., Otiti, T., Beye, A. C., Harmer, M. P., Kiely, C. J., Warren, W., Haataja, M. P., & Soboyejo, W. O. (2009). LHRH-functionalized superparamagnetic iron oxide nanoparticles for breast cancer targeting and contrast enhancement in MRI. *Materials Science and Engineering: C*, *29*(4), 1467-1479. https://doi.org/https://doi.org/10.1016/j.msec.2008.09.039

Miola, M., Fucale, G., Maina, G., & Verné, E. (2015). Antibacterial and bioactive composite bone cements containing surface silver-doped glass particles. *Biomedical Materials*, *10*(5), 055014.

Miyazawa, T., Itaya, M., Burdeos, G. C., Nakagawa, K., & Miyazawa, T. (2021). A critical review of the use of surfactant-coated nanoparticles in nanomedicine and food nanotechnology. *International journal of nanomedicine*, 3937-3999.

Mohanty, S., Mishra, S., Jena, P., Jacob, B., Sarkar, B., & Sonawane, A. (2012). An investigation on the antibacterial, cytotoxic, and antibiofilm efficacy of starch-stabilized silver nanoparticles. *Nanomedicine: Nanotechnology, Biology Medicine*, *8*(6), 916-924.

Moreno-Sastre, M., Pastor, M., Esquisabel, A., Sans, E., Viñas, M., Fleischer, A., Palomino, E., Bachiller, D., & Pedraz, J. L. (2016). Pulmonary delivery of tobramycin-loaded nanostructured lipid carriers for Pseudomonas aeruginosa infections associated with cystic fibrosis. *International journal of pharmaceutics*, *498*(1-2), 263-273.

Mousa, S. A., & Bharali, D. J. (2011). Nanotechnology-Based Detection and Targeted Therapy in Cancer: Nano-Bio Paradigms and Applications. *3*(3), 2888-2903. https://www.mdpi.com/2072-6694/3/3/2888

Mousazadeh, H., Pilehvar-Soltanahmadi, Y., Dadashpour, M., & Zarghami, N. (2021). Cyclodextrin based natural nanostructured carbohydrate polymers as effective non-viral siRNA delivery systems for cancer gene therapy. *Journal of Controlled Release*, *330*, 1046-1070.

Mukha, I. P., Eremenko, A., Smirnova, N., Mikhienkova, A., Korchak, G., Gorchev, V., & Chunikhin, A. Y. (2013). Antimicrobial activity of stable silver nanoparticles of a certain size. *Applied biochemistry microbiology*, *49*, 199-206.

Murugan, C., Lee, H., & Park, S. (2023). Tumor-targeted molybdenum disulfide@ barium titanate core–shell nanomedicine for dual photothermal and chemotherapy of triple-negative breast cancer cells. *Journal of Materials Chemistry B*, *11*(5), 1044-1056.

Niemirowicz, K., Swiecicka, I., Wilczewska, A. Z., Misztalewska, I., Kalska-Szostko, B., Bienias, K., Bucki, R., & Car, H. (2014). Gold-functionalized magnetic nanoparticles restrict growth of Pseudomonas aeruginosa. *International journal of nanomedicine*, 2217-2224.

Nowinski, R. J., Gillespie, R. J., Shishani, Y., Cohen, B., Walch, G., & Gobezie, R. (2012). Antibiotic-loaded bone cement reduces deep infection rates for primary reverse total shoulder arthroplasty: a retrospective, cohort study of 501 shoulders. *Journal of shoulder elbow surgery*, *21*(3), 324-328.

Ou, L., Song, B., Liang, H., Liu, J., Feng, X., Deng, B., Sun, T., & Shao, L. (2016). Toxicity of graphene-family nanoparticles: a general review of the origins and mechanisms. *Particle fibre toxicology*, *13*(1), 1-24.

Padmavathy, N., & Vijayaraghavan, R. (2011). Interaction of ZnO nanoparticles with microbes—a physio and biochemical assay. *Journal of biomedical nanotechnology*, *7*(6), 813-822.

Pan, W.-Y., Huang, C.-C., Lin, T.-T., Hu, H.-Y., Lin, W.-C., Li, M.-J., & Sung, H.-W. (2016). Synergistic antibacterial effects of localized heat and oxidative stress caused by hydroxyl radicals mediated by graphene/iron oxide-based nanocomposites. *Nanomedicine: Nanotechnology, Biology Medicine*, *12*(2), 431-438.

Parveen, S., Yadav, N., & Banerjee, M. (2020). Nano-Based Drug Delivery Tools for Personalized Nanomedicine. *Nanomaterials Environmental Biotechnology*, 189-199.

Pelgrift, R. Y., & Friedman, A. J. (2013). Nanotechnology as a therapeutic tool to combat microbial resistance. *Advanced Drug Delivery Reviews*, *65*(13-14), 1803-1815.

Peng, Z., Ni, J., Zheng, K., Shen, Y., Wang, X., He, G., Jin, S., & Tang, T. (2013). Dual effects and mechanism of TiO2 nanotube arrays in reducing bacterial colonization and enhancing C3H10T1/2 cell adhesion. *International journal of nanomedicine*, 3093-3105.

Pereira, L., Dias, N., Carvalho, J., Fernandes, S., Santos, C., & Lima, N. (2014). Synthesis, characterization and antifungal activity of chemically and fungal-produced silver nanoparticles against Trichophyton rubrum. *Journal of applied microbiology*, *117*(6), 1601-1613.

Ramalingam, B., Parandhaman, T., & Das, S. K. (2016). Antibacterial effects of biosynthesized silver nanoparticles on surface ultrastructure and nanomechanical properties of gram-negative bacteria viz. Escherichia coli and Pseudomonas aeruginosa. *ACS Applied Materials Interfaces*, *8*(7), 4963-4976.

Ramazanzadeh, B., Jahanbin, A., Yaghoubi, M., Shahtahmassbi, N., Ghazvini, K., Shakeri, M., & Shafaee, H. (2015). Comparison of antibacterial effects of ZnO and CuO nanoparticles coated brackets against Streptococcus mutans. *Journal of Dentistry*, *16*(3), 200.

Rani, S., & Gupta, U. (2020). HPMA-based polymeric conjugates in anticancer therapeutics. *Drug discovery today*, *25*(6), 997-1012.

Raposo, G., & Stoorvogel, W. (2013). Extracellular vesicles: Exosomes, microvesicles, and friends. *Journal of Cell Biology*, *200*(4), 373-383. https://doi.org/10.1083/jcb.201211138 %J Journal of Cell Biology

Rijcken, C. J., De Lorenzi, F., Biancacci, I., Hanssen, R. G., Thewissen, M., Hu, Q., Atrafi, F., Liskamp, R. M., Mathijssen, R. H., & Miedema, I. H. (2022). Design, development and clinical translation of CriPec®-based core-crosslinked polymeric micelles. *Advanced Drug Delivery Reviews*, 114613.

Rout, S. K., Priya, V., Setia, A., Mehata, A. K., Mohan, S., Albratty, M., Najmi, A., Meraya, A. M., Makeen, H. A., & Tambuwala, M. M. (2022). Mitochondrial targeting theranostic nanomedicine and molecular biomarkers for efficient cancer diagnosis and therapy. *Biomedicine Pharmacotherapy*, *153*, 113451.

Samadian, H., Mohammad-Rezaei, R., Jahanban-Esfahlan, R., Massoumi, B., Abbasian, M., Jafarizad, A., & Jaymand, M. (2020). A de novo theranostic nanomedicine composed of PEGylated graphene oxide and gold nanoparticles for cancer therapy. *Journal of Materials Research*, *35*(4), 430-441.

Samuel, U., & Guggenbichler, J. (2004). Prevention of catheter-related infections: the potential of a new nano-silver impregnated catheter. *International journal of antimicrobial agents*, *23*, 75-78.

Sarwar, A., Katas, H., Samsudin, S. N., & Zin, N. M. (2015). Regioselective sequential modification of chitosan via azide-alkyne click reaction: synthesis, characterization, and antimicrobial activity of chitosan derivatives and nanoparticles. *PLoS One*, *10*(4), e0123084.

Shah, S. S., Shaikh, M. N., Khan, M. Y., Alfasane, M. A., Rahman, M. M., & Aziz, M. A. (2021). Present status and future prospects of jute in nanotechnology: A review. *The Chemical Record*, *21*(7), 1631-1665.

Shim, M. K., Yang, S., Sun, I.-C., & Kim, K. (2022). Tumor-activated carrier-free prodrug nanoparticles for targeted cancer Immunotherapy: Preclinical evidence for safe and effective drug delivery. *Advanced Drug Delivery Reviews*, *183*, 114177.

Shinde, S. S. (2015). Antimicrobial activity of ZnO nanoparticles against pathogenic bacteria and fungi. *Sci Med Central*, *3*, 1033.

Shrivastava, S., Bera, T., Roy, A., Singh, G., Ramachandrarao, P., & Dash, D. (2007). Characterization of enhanced antibacterial effects of novel silver nanoparticles. *Nanotechnology*, *18*(22), 225103.

Sievers, E. L., & Senter, P. D. (2013). Antibody-Drug Conjugates in Cancer Therapy. *64*(1), 15-29. https://doi.org/10.1146/annurev-med-050311-201823

Sohail, M., Sun, Z., Li, Y., Gu, X., & Xu, H. (2021). Research progress in strategies to improve the efficacy and safety of doxorubicin for cancer chemotherapy. *Expert review of anticancer therapy*, *21*(12), 1385-1398.

Sondi, I., & Salopek-Sondi, B. (2004). Silver nanoparticles as antimicrobial agent: a case study on E. coli as a model for Gram-negative bacteria. *Journal of colloid interface science*, *275*(1), 177-182.

Su, H.-L., Chou, C.-C., Hung, D.-J., Lin, S.-H., Pao, I.-C., Lin, J.-H., Huang, F.-L., Dong, R.-X., & Lin, J.-J. (2009). The disruption of bacterial membrane integrity through ROS generation induced by nanohybrids of silver and clay. *Biomaterials Biosystems*, *30*(30), 5979-5987.

Swaminathan, S., Pastero, L., Serpe, L., Trotta, F., Vavia, P., Aquilano, D., Trotta, M., Zara, G., & Cavalli, R. (2010). Cyclodextrin-based nanosponges encapsulating camptothecin: Physicochemical characterization, stability and cytotoxicity. *European Journal of Pharmaceutics Biopharmaceutics*, *74*(2), 193-201.

Tabata, Y., Murakami, Y., & Ikada, Y. (1997). Photodynamic effect of polyethylene glycol–modified fullerene on tumor. *Japanese Journal of Cancer Research*, *88*(11), 1108-1116.

Tabish, T. A., & Hamblin, M. R. (2021). Mitochondria-targeted nanoparticles (mitoNANO): An emerging therapeutic shortcut for cancer. *Biomaterials Biosystems*, *3*, 100023.

Takakura, Y., & Takahashi, Y. (2022). Strategies for persistent retention of macromolecules and nanoparticles in the blood circulation. *Journal of Controlled Release*, *350*, 486-493.

Tang, L., Wang, Z., Mu, Q., Yu, Z., Jacobson, O., Li, L., Yang, W., Huang, C., Kang, F., & Fan, W. (2020). Targeting neutrophils for enhanced cancer theranostics. *Advanced Materials*, *32*(33), 2002739.

Thayath, J., Pavithran, K., Nair, S. V., & Koyakutty, M. (2021a). Cancer nanomedicine developed from total human serum: a novel approach for making personalized nanomedicine. *Nanomedicine: nanotechnology, biology, medicine*, *16*(12), 997-1015.

Thayath, J., Pavithran, K., Nair, S. V., & Koyakutty, M. (2021b). Cancer nanomedicine developed from total human serum: a novel approach for making personalized nanomedicine. *Nanomedicine*, *16*(12), 997-1015.

Wang, L., Hu, C., & Shao, L. J. I. j. o. n. (2017). The antimicrobial activity of nanoparticles: present situation and prospects for the future. 1227-1249.

Wang, R., Deng, J., He, D., Yang, E., Yang, W., Shi, D., Jiang, Y., Qiu, Z., Webster, T. J., & Shen, Y. (2021). Corrigendum to" PEGylated hollow gold nanoparticles for combined X-ray radiation and photothermal therapy in vitro and enhanced CT imaging"[Nanomedicine: Nanotechnology, Biology, and Medicine 16 (2019) 195-205 NANO 1919]. *Nanomedicine: nanotechnology, biology, medicine*, *35*, 102313.

Wang, X., Liu, X., Li, Y., Wang, P., Feng, X., Liu, Q., Yan, F., & Zheng, H. (2017). Sensitivity to antitubulin chemotherapeutics is potentiated by a photoactivable nanoliposome. *Biomaterials*, *141*, 50-62. https://doi.org/https://doi.org/10.1016/j.biomaterials.2017.06.034

Wehling, J., Dringen, R., Zare, R. N., Maas, M., & Rezwan, K. (2014). Bactericidal activity of partially oxidized nanodiamonds. *ACS nano*, *8*(6), 6475-6483.

Wilking, J. N., Zaburdaev, V., De Volder, M., Losick, R., Brenner, M. P., & Weitz, D. A. (2013). Liquid transport facilitated by channels in Bacillus subtilis biofilms. *Proceedings of the National Academy of Sciences*, *110*(3), 848-852.

Wu, B., Zhuang, W.-Q., Sahu, M., Biswas, P., & Tang, Y. J. (2011). Cu-doped TiO2 nanoparticles enhance survival of Shewanella oneidensis MR-1 under Ultraviolet Light (UV) exposure. *Science of the total environment*, *409*(21), 4635-4639.

Xia, W., Grandfield, K., Hoess, A., Ballo, A., Cai, Y., & Engqvist, H. (2012). Mesoporous titanium dioxide coating for metallic implants. *Journal of Biomedical Materials Research Part B: Applied Biomaterials*, *100*(1), 82-93.

Xu, X., Xu, L., Wen, C., Xia, J., Zhang, Y., & Liang, Y. (2023). Programming assembly of biomimetic exosomes: an emerging theranostic nanomedicine platform. *Materials Today Bio*, 100760.

Xu, Y., Wei, M.-T., Ou-Yang, H. D., Walker, S. G., Wang, H. Z., Gordon, C. R., Guterman, S., Zawacki, E., Applebaum, E., & Brink, P. R. (2016). Exposure to TiO2 nanoparticles increases Staphylococcus aureus infection of HeLa cells. *Journal of nanobiotechnology*, *14*(1), 1-16.

Xu, Z. P., Zeng, Q. H., Lu, G. Q., & Yu, A. B. (2006). Inorganic nanoparticles as carriers for efficient cellular delivery. *Chemical Engineering Science*, *61*(3), 1027-1040. https://doi.org/https://doi.org/10.1016/j.ces.2005.06.019

Yu, C., Hu, Z.-Q., & Peng, R.-Y. (2014). Effects and mechanisms of a microcurrent dressing on skin wound healing: a review. *Military Medical Research*, *1*(1), 1-8.

Yu, J., Zhang, W., Li, Y., Wang, G., Yang, L., Jin, J., Chen, Q., & Huang, M. (2014). Synthesis, characterization, antimicrobial activity and mechanism of a novel hydroxyapatite whisker/nano zinc oxide biomaterial. *Biomedical Materials*, *10*(1), 015001.

Zhang, L., Gu, F., Chan, J., Wang, A., Langer, R., & Farokhzad, O. (2008). Nanoparticles in Medicine: Therapeutic Applications and Developments. *83*(5), 761-769. https://doi.org/https://doi.org/10.1038/sj.clpt.6100400

Zhang, W., Li, Y., Niu, J., & Chen, Y. (2013). Photogeneration of reactive oxygen species on uncoated silver, gold, nickel, and silicon nanoparticles and their antibacterial effects. *Langmuir*, *29*(15), 4647-4651.

Zhao, L., & Ashraf, M. (2015). Influence of silver-hydroxyapatite nanocomposite coating on biofilm formation of joint prosthesis and its mechanism. *The West Indian Medical Journal*, *64*(5), 506.

Zhao, X., Hilliard, L. R., Mechery, S. J., Wang, Y., Bagwe, R. P., Jin, S., & Tan, W. (2004). A rapid bioassay for single bacterial cell quantitation using bioconjugated nanoparticles. *101*(42), 15027-15032. https://doi.org/doi:10.1073/pnas.0404806101

Zhao, Z., Ukidve, A., Kim, J., & Mitragotri, S. (2020). Targeting strategies for tissue-specific drug delivery. *Cell*, *181*(1), 151-167.

Zhou, Y., Li, L., Zhou, Q., Yuan, S., Wu, Y., Zhao, H., & Wu, H. (2015). Lack of efficacy of prophylactic application of antibiotic-loaded bone cement for prevention of infection in primary total knee arthroplasty: results of a meta-analysis. *Surgical Infections*, *16*(2), 183-187.

Zi, Y., Yang, K., He, J., Wu, Z., Liu, J., & Zhang, W. (2022). Strategies to enhance drug delivery to solid tumors by harnessing the EPR effects and alternative targeting mechanisms. *Advanced Drug Delivery Reviews*, 114449.

BÖLÜM 5

Nanopartiküllerin Hücre ve Moleküler Biyolojik Uygulamaları

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GİRİŞ

Nanoteknoloji, son yıllarda endüstri, sanayi, biyomedikal gibi çok farklı uygulama alanlarında yerini alan bir bilim dalı olup, biyoloji ve biyomedikal araştırmalarının en yaygın kullanım alanlarındandır (Allhoff ve ark., 2009). Nanopartiküller, birbirinden çok farklı boyut, şekil, içerik ve yüzey yapısı ile tasarlanabilen, biyolojik uygulamalarda gösterdikleri özellikleri ve etkileriyle yeni tekniklerin sağlanması ve temel biyolojik soruların araştırılmasında umut vaat edici yapılardır. Nanopartiküller (NP) araştırmalarda kullanılmak üzere yeni araç ve kullanımlar sunacak şekilde içerik ve işlevlere sahip olarak tasarlanabilir ve bu amaçla tasarlanan yeni özellikli NP'ler hücre düzeyinde biyolojik süreç görüntülemesi, analit tespiti gibi uygulamalarda kullanılabilmektedir. Bu bölümde, farklı nanopartikül türlerinin hedeflenmesi, ilaç dağıtımı, görüntüleme, algılama ve biyolojik süreçlerin hücre ve doku düzeyinde incelenmesindeki kullanımı ve moleküler düzeyde biyolojik uygulamalardaki yerleri tartışılacaktır.

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bileşiklerin bağlanmasına veya reaksiyona girmesine izin vererek moleküler görüntüleme ve algılama sinyallerini geliştirir. Spesifik olmayan hedefleme ve hidrofobik maddelerin sulu ortamlardaki çözünmezliği ve kararsızlığı, biyolojik araştırmalarda NP'lerin yardımıyla çözülebilecek geleneksel dağıtım yöntemlerinin diğer iki dezavantajıdır. Biyolojik sistemlerin nano ölçekte incelenmesindeki kayda değer ilerlemeler ve proteomik ve genomiğin nanoteknoloji ile birleştirilmesi sayesinde hücre fonksiyonu ve süreçlerinin daha iyi anlaşılması mümkündür. Bu anlayış, moleküler sistemleri hastalık sonrası bozulmuş durumlarına geri getirebilecek yeni nano ölçekli araçların yaratılmasına yardımcı olabilir.

Düşük analit konsantrasyonu tespit uygulamalarında ve ayrıca floresans ve manyetik rezonans görüntüleme gibi tekniklerde kontrast ajanlarında kullanılmak üzere günümüzde çok çeşitli ticari NP'ler mevcuttur. Bununla birlikte, yüzey yükü, boyut, fonksiyonel grup, şekil, ve bileşim dahil olmak üzere NP'nin biyolojik sistemlerle nasıl etkileşime girdiğini etkileyebilecek bir dizi NP özelliği vardır. Dolayısıyla NP'lerin biyolojik uygulamalar için kullanılması, biyolojik sistemlerde çeşitli NP formülasyonlarının ürettiği toksisite gibi etkilerin kapsamlı bir şekilde değerlendirilmesini gerektirir. Biyoloji çalışan araştırmacıların NP teknolojisinden tam olarak yararlanabilmesi için kimyagerlerin ve nanoteknoloji uzmanlarının NP üretim süreçlerini standartlaştırması ve kolaylaştırması gerekir. Yeni uygulama alanları ve sinerjiler bulmak için biyologların nanoteknoloji uzmanlarıyla aktif olarak etkileşime geçmesi ve iş birliği yapması da gerekecektir.

Kaynaklar

AbdelatifAbdelaziz, A., Saafan, A. M., & Abdelgawad, L. M. (2021). Phototherapy with gold nanoparticles and a diode laser for oral squamous cell carcinoma of the tongue in rats. *Annals of the Romanian Society for Cell Biology*, *25*(6), 7570-7585.

Abdellatif, A. A., Younis, M. A., Alsharidah, M., Al Rugaie, O., & Tawfeek, H. M. (2022). Biomedical applications of quantum dots: overview, challenges, and clinical potential. *International journal of nanomedicine*, 1951-1970.

Agarwal, K. (2022). Liposome Assisted Drug Delivery: An Updated Review. *Indian Journal of Pharmaceutical Sciences*, *84*(4).

Aisida, S. O., Akpa, P. A., Ahmad, I., Zhao, T.-k., Maaza, M., & Ezema, F. I. (2020). Bio-inspired encapsulation and functionalization of iron oxide nanoparticles for biomedical applications. *European Polymer Journal*, *122*, 109371.

Albanese, A., Tang, P. S., & Chan, W. C. (2012). The effect of nanoparticle size, shape, and surface chemistry on biological systems. *Annual review of biomedical engineering*, *14*, 1-16.

Alexis, F., Pridgen, E., Molnar, L. K., & Farokhzad, O. C. (2008). Factors affecting the clearance and biodistribution of polymeric nanoparticles. *Molecular pharmaceutics*, *5*(4), 505-515.

Allhoff, F., Lin, P., & Moore, D. (2009). *What is nanotechnology and why does it matter?: from science to ethics*. John Wiley & Sons.

Alsaab, H. O., Alghamdi, M. S., Alotaibi, A. S., Alzhrani, R., Alwuthaynani, F., Althobaiti, Y. S., Almalki, A. H., Sau, S., & Iyer, A. K. (2020). Progress in clinical trials of photodynamic therapy for solid tumors and the role of nanomedicine. *Cancers*, *12*(10), 2793.

Aluri, S. R. (2022). Protein and Peptide-Based Therapeutics for Cancer Imaging. In *Nanomaterials for Cancer Detection Using Imaging Techniques and Their Clinical Applications* (pp. 441-471). Springer.

Andreadou, M., Liandris, E., Gazouli, M., Mataragka, A., Tachtsidis, I., Goutas, N., Vlachodimitropoulos, D., & Ikonomopoulos, J. (2016). Detection of Leishmania-specific DNA and surface antigens using a combination of functionalized magnetic beads and cadmium selenite quantum dots. *Journal of microbiological methods*, *123*, 62-67.

Bai, X., Wang, Y., Song, Z., Feng, Y., Chen, Y., Zhang, D., & Feng, L. (2020). The basic properties of gold nanoparticles and their applications in tumor diagnosis and treatment. *International journal of molecular sciences*, *21*(7), 2480.

Bailey-Hytholt, C. M., Nagarajan, R., & Camesano, T. A. (2020). Förster Resonance Energy Transfer Probing of Assembly and Disassembly of Short Interfering RNA/Poly (ethylene glycol)–Poly-L-Lysine Polyion Complex Micelles. In *Molecular Assemblies: Characterization and Applications* (pp. 47-60). ACS Publications.

Bailey, R. E., Smith, A. M., & Nie, S. (2004). Quantum dots in biology and medicine. *Physica E: Low-dimensional Systems and Nanostructures*, *25*(1), 1-12.

Bajaj, A., Miranda, O. R., Kim, I.-B., Phillips, R. L., Jerry, D. J., Bunz, U. H., & Rotello, V. M. (2009). Detection and differentiation of normal, cancerous, and metastatic cells using nanoparticle-polymer sensor arrays. *Proceedings of the National Academy of Sciences*, *106*(27), 10912-10916.

Bajaj, A., Rana, S., Miranda, O. R., Yawe, J. C., Jerry, D. J., Bunz, U. H., & Rotello, V. M. (2010). Cell surface-based differentiation of cell types and cancer states using a gold nanoparticle-GFP based sensing array. *Chemical Science*, *1*(1), 134-138.

Bamrungsap, S., Zhao, Z., Chen, T., Wang, L., Li, C., Fu, T., & Tan, W. (2012). Nanotechnology in therapeutics: a focus on nanoparticles as a drug delivery system. *Nanomedicine*, *7*(8), 1253-1271.

Bangham, A. (1993). Liposomes: the Babraham connection. *Chemistry and physics of lipids*, *64*(1-3), 275-285.

Bareford, L. M., & Swaan, P. W. (2007). Endocytic mechanisms for targeted drug delivery. *Advanced Drug Delivery Reviews*, *59*(8), 748-758.

Breunig, M., Bauer, S., & Göpferich, A. (2008). Polymers and nanoparticles: intelligent tools for intracellular targeting? *European Journal of Pharmaceutics and Biopharmaceutics*, *68*(1), 112-128.

Bruce, N., Farrell, F., Xie, E., Scullion, M. G., Haughey, A.-M., Gu, E., Dawson, M. D., & Laurand, N. (2023). MicroLED biosensor with colloidal quantum dots and smartphone detection. *Biomedical Optics Express*, *14*(3), 1107-1118.

Bulte, J. W., Wang, C., & Shakeri-Zadeh, A. (2022). In vivo cellular magnetic imaging: Labeled versus unlabeled cells. *Advanced Functional Materials*, *32*(50), 2207626.

Cecchini, M. P., Turek, V. A., Paget, J., Kornyshev, A. A., & Edel, J. B. (2013). Self-assembled nanoparticle arrays for multiphase trace analyte detection. *Nature materials*, *12*(2), 165-171.

Chang, C.-C., Chen, C.-P., Wu, T.-H., Yang, C.-H., Lin, C.-W., & Chen, C.-Y. (2019). Gold nanoparticle-based colorimetric strategies for chemical and biological sensing applications. *Nanomaterials*, *9*(6), 861.

Chang, C., Guo, W., Yu, X., Guo, C., Zhou, N., Guo, X., Huang, R.-L., Li, Q., & Zhu, Y. (2023). Engineered M13 phage as a novel therapeutic bionanomaterial for clinical applications: From tissue regeneration to cancer therapy. *Materials Today Bio*, 100612.

Chauhan, V., Stylianopoulos, T., Martin, J., & Popović, Z. (2012). Chen o. *Kamoun WS, Bawendi Mg, Fukumura D and Jain RK: normalization of tumour blood vessels improves the delivery of nanomedicines in a size-dependent manner. nat nanotechnol*, *7*, 383-388.

Chen, R., Sun, Y., Huo, B., Yuan, S., Sun, X., Zhang, M., Yin, N., Fan, L., Yao, W., & Wang, J. (2020). Highly sensitive detection of ochratoxin A based on bio-barcode immunoassay and catalytic hairpin assembly signal amplification. *Talanta*, *208*, 120405.

Cheng, Y., Sun, C., Liu, R., Yang, J., Dai, J., Zhai, T., Lou, X., & Xia, F. (2019). A multifunctional peptide-conjugated AIEgen for efficient and sequential targeted gene delivery into the nucleus. *Angewandte Chemie*, *131*(15), 5103-5107.

Cho, M. H., Lee, E. J., Son, M., Lee, J.-H., Yoo, D., Kim, J.-w., Park, S. W., Shin, J.-S., & Cheon, J. (2012). A magnetic switch for the control of cell death signalling in in vitro and in vivo systems. *Nature materials*, *11*(12), 1038-1043.

Coiffier, B., Lepage, E., Brière, J., Herbrecht, R., Tilly, H., Bouabdallah, R., Morel, P., Van Den Neste, E., Salles, G., & Gaulard, P. (2002). CHOP chemotherapy plus rituximab compared with CHOP alone in elderly patients with diffuse large-B-cell lymphoma. *New England Journal of Medicine*, *346*(4), 235-242.

De Leo, V., Maurelli, A. M., Giotta, L., & Catucci, L. (2022). Liposomes containing nanoparticles: preparation and applications. *Colloids and Surfaces B: Biointerfaces*, 112737.

Dreaden, E. C., Alkilany, A. M., Huang, X., Murphy, C. J., & El-Sayed, M. A. (2012). The golden age: gold nanoparticles for biomedicine. *Chemical Society Reviews*, *41*(7), 2740-2779.

DuRoss, A. N., Neufeld, M. J., Rana, S., Thomas Jr, C. R., & Sun, C. (2019). Integrating nanomedicine into clinical radiotherapy regimens. *Advanced drug delivery reviews*, *144*, 35-56.

Eivazzadeh-Keihan, R., Bahreinizad, H., Amiri, Z., Aliabadi, H. A. M., Salimi-Bani, M., Nakisa, A., Davoodi, F., Tahmasebi, B., Ahmadpour, F., & Radinekiyan, F. (2021). Functionalized magnetic nanoparticles for the separation and purification of proteins and peptides. *TrAC Trends in Analytical Chemistry*, *141*, 116291.

Etoc, F., Lisse, D., Bellaiche, Y., Piehler, J., Coppey, M., & Dahan, M. (2013). Subcellular control of Rac-GTPase signalling by magnetogenetic manipulation inside living cells. *Nature nanotechnology*, *8*(3), 193-198.

Felgner, P. L., Gadek, T. R., Holm, M., Roman, R., Chan, H. W., Wenz, M., Northrop, J. P., Ringold, G. M., & Danielsen, M. (1987). Lipofection: a highly efficient, lipid-mediated DNA-transfection procedure. *Proceedings of the National Academy of Sciences*, *84*(21), 7413-7417.

Felgner, P. L., & Ringold, G. (1989). Cationic liposome-mediated transfection. *Nature*, *337*(6205), 387-388.

Ferraro, S., Bussetti, M., Bassani, N., Rossi, R. S., Incarbone, G. P., Bianchi, F., Maggioni, M., Runza, L., Ceriotti, F., & Panteghini, M. (2021). Definition of outcome-based prostate-specific antigen (PSA) thresholds for advanced prostate cancer risk prediction. *Cancers*, *13*(14), 3381.

Fornara, A., Johansson, P., Petersson, K., Gustafsson, S., Qin, J., Olsson, E., Ilver, D., Krozer, A., Muhammed, M., & Johansson, C. (2008). Tailored magnetic nanoparticles for direct and sensitive detection of biomolecules in biological samples. *Nano Letters*, *8*(10), 3423-3428.

Fu, A., Hu, W., Xu, L., Wilson, R. J., Yu, H., Osterfeld, S. J., Gambhir, S. S., & Wang, S. X. (2009). Protein-functionalized synthetic antiferromagnetic nanoparticles for biomolecule detection and magnetic manipulation. *Angewandte Chemie International Edition*, *48*(9), 1620-1624.

Gahtori, P., Mishra, A., Varanasi, S. R., & Pandey, R. (2023). Unravelling the Mechanism behind Charge Reversal at Silica Nanoparticle–Model Cell Membrane Interfaces. *The Journal of Physical Chemistry B*, *127*(18), 4072-4080.

Ganji, C., Muppala, V., Khan, M., Nagaraju, G. P., & Farran, B. (2023). Mitochondrial-targeted nanoparticles: Delivery and therapeutic agents in cancer. *Drug Discovery Today*, *28*(3), 103469.

Gao, Y., Zhang, C., Yang, Y., Yang, N., Lu, S., You, T., & Yin, P. (2021). A high sensitive glucose sensor based on Ag nanodendrites/Cu mesh substrate via surface-enhanced Raman spectroscopy and electrochemical analysis. *Journal of Alloys and Compounds*, *863*, 158758.

Gaster, R. S., Hall, D. A., Nielsen, C. H., Osterfeld, S. J., Yu, H., Mach, K. E., Wilson, R. J., Murmann, B., Liao, J. C., & Gambhir, S. S. (2009). Matrix-insensitive protein assays push the limits of biosensors in medicine. *Nature medicine*, *15*(11), 1327-1332.

Georganopoulou, D. G., Chang, L., Nam, J.-M., Thaxton, C. S., Mufson, E. J., Klein, W. L., & Mirkina, C. A. (2020). Nanoparticle-Based Detection in Cerebral Spinal Fluid of a Soluble Pathogenic Biomarker for Alzheimer's Disease. In *Spherical Nucleic Acids* (pp. 1509-1521). Jenny Stanford Publishing.

Ghareghomi, S., Ahmadian, S., Zarghami, N., & Hemmati, S. (2021). hTERT-molecular targeted therapy of ovarian cancer cells via folate-functionalized PLGA nanoparticles co-loaded with MNPs/siRNA/wortmannin. *Life Sciences*, *277*, 119621.

Giljohann, D. A., Seferos, D. S., Daniel, W. L., Massich, M. D., Patel, P. C., & Mirkin, C. A. (2020). Gold nanoparticles for biology and medicine. *Spherical Nucleic Acids*, 55-90.

Giron, F., Pastó, A., Tasciotti, E., & Abraham, B. P. (2019). Nanotechnology in the treatment of inflammatory bowel disease. *Inflammatory bowel diseases*, *25*(12), 1871-1880.

Gonçalves, S., Martins, I. C., & Santos, N. C. (2022). Nanoparticle-peptide conjugates for bacterial detection and neutralization: Potential applications in diagnostics and therapy. *Wiley Interdisciplinary Reviews: Nanomedicine and Nanobiotechnology*, *14*(6), e1819.

Gong, L., Weng, Y., Zhou, W., Zhang, K., Li, W., Jiang, J., & Zhu, J. (2021). In vivo CT imaging of gold nanoparticle-labeled exosomes in a myocardial infarction mouse model. *Annals of Translational Medicine*, *9*(6).

Govindaraju, S., Reddy, A. S., Kim, J., & Yun, K. (2019). Sensitive detection of epinephrine in human serum via fluorescence enhancement of gold nanoclusters. *Applied Surface Science*, *498*, 143837.

Gradishar, W. J., Tjulandin, S., Davidson, N., Shaw, H., Desai, N., Bhar, P., Hawkins, M., & O'Shaughnessy, J. (2005). Phase III trial of nanoparticle albumin-bound paclitaxel compared with polyethylated castor oil–based paclitaxel in women with breast cancer. *Journal of clinical oncology*, *23*(31), 7794-7803.

Gref, R., Minamitake, Y., Peracchia, M. T., Trubetskoy, V., Torchilin, V., & Langer, R. (1994). Biodegradable long-circulating polymeric nanospheres. *Science*, *263*(5153), 1600-1603.

Guan, X., Wang, L., Li, Z., Liu, M., Wang, K., Lin, B., Yang, X., Lai, S., & Lei, Z. (2019). Preparation of multi-stimulus responsive polymer nanospheres based on AIE effect and its cell tracing application. *Acta Chimica Sinica*, *77*(10), 1036.

Gui, L., Zhang, X. H., Qiao, Z. Y., & Wang, H. (2020). Cell-penetrating peptides and polymers for improved drug delivery. *ChemNanoMat*, *6*(8), 1138-1148.

Gurudatt, N., Chung, S., Kim, J.-M., Kim, M.-H., Jung, D.-K., Han, J.-Y., & Shim, Y.-B. (2019). Separation detection of different circulating tumor cells in the blood using an electrochemical microfluidic channel modified with a lipid-bonded conducting polymer. *Biosensors and Bioelectronics*, *146*, 111746.

Hammami, I., & Alabdallah, N. M. (2021). Gold nanoparticles: Synthesis properties and applications. *Journal of king Saud university-science*, *33*(7), 101560.

Hasan, M. T., Gonzalez-Rodriguez, R., Lin, C. W., Campbell, E., Vasireddy, S., Tsedev, U., Belcher, A. M., & Naumov, A. V. (2020). Rare-earth metal ions doped graphene quantum dots for near-ir in vitro/in vivo/ex vivo imaging applications. *Advanced Optical Materials*, *8*(21), 2000897.

Hashida, M. (2022). Advocation and advancements of EPR effect theory in drug delivery science: A commentary. In (Vol. 346, pp. 355-357): Elsevier.
Haun, J. B., Yoon, T. J., Lee, H., & Weissleder, R. (2010). Magnetic nanoparticle biosensors. *Wiley Interdisciplinary Reviews: Nanomedicine and Nanobiotechnology*, *2*(3), 291-304.
Hawkins, M. J., Soon-Shiong, P., & Desai, N. (2008). Protein nanoparticles as drug carriers in clinical medicine. *Advanced drug delivery reviews*, *60*(8), 876-885.
Herd, H. L., Bartlett, K. T., Gustafson, J. A., McGill, L. D., & Ghandehari, H. (2015). Macrophage silica nanoparticle response is phenotypically dependent. *Biomaterials*, *53*, 574-582.
Hernández-Hernández, A. A., Aguirre-Álvarez, G., Cariño-Cortés, R., Mendoza-Huizar, L. H., & Jiménez-Alvarado, R. (2020). Iron oxide nanoparticles: synthesis, functionalization, and applications in diagnosis and treatment of cancer. *Chemical Papers*, *74*(11), 3809-3824.
Hosseini, S., Mohammadnejad, J., Salamat, S., Zadeh, Z. B., Tanhaei, M., & Ramakrishna, S. (2023). Theranostic polymeric nanoparticles as a new approach in cancer therapy and diagnosis: a review. *Materials Today Chemistry*, *29*, 101400.
Hou, Y., Ruipeng, C., Wang, Z., Lu, R., Wang, Y., Ren, S., Li, S., Wang, Y., Han, T., & Yang, S. (2023). Bio-barcode assay: A useful technology for ultrasensitive and logic-controlled specific detection in food safety: A review. *Analytica Chimica Acta*, 341351.
Hu, J., Obayemi, J., Malatesta, K., Yurkow, E., Adler, D., & Soboyejo, W. (2020). Luteinizing hormone-releasing hormone (LHRH) conjugated magnetite nanoparticles as MRI contrast agents for breast cancer imaging. *Applied Sciences*, *10*(15), 5175.
Huang, T., Yang, J., Zhou, W., Liu, X., Pan, Y., & Song, Y. (2019). Rapid identification of urinary tract infections based on ultrasensitive bacteria detection using volumetric bar-chart chip. *Sensors and Actuators B: Chemical*, *298*, 126885.
Israel, L. L., Galstyan, A., Holler, E., & Ljubimova, J. Y. (2020). Magnetic iron oxide nanoparticles for imaging, targeting and treatment of primary and metastatic tumors of the brain. *Journal of Controlled Release*, *320*, 45-62.
Jain, D., Prajapati, S. K., Jain, A., & Singhal, R. (2023). Nano-formulated siRNA-based therapeutic approaches for cancer therapy. *Nano Trends*, *1*, 100006.
Jeon, M., Halbert, M. V., Stephen, Z. R., & Zhang, M. (2021). Iron oxide nanoparticles as T1 contrast agents for magnetic resonance imaging: fundamentals, challenges, applications, and prospectives. *Advanced Materials*, *33*(23), 1906539.
Ji, Y., Li, Y.-M., Seo, J. G., Jang, T.-S., Knowles, J. C., Song, S. H., & Lee, J.-H. (2021). Biological potential of polyethylene glycol (PEG)-functionalized graphene quantum dots in in vitro neural stem/progenitor cells. *Nanomaterials*, *11*(6), 1446.
Kale, K., Fulfager, A., Juvale, K., & Yadav, K. S. (2022). Long circulating polymeric nanoparticles of gemcitabine HCl using PLGA-PEG-PPG-PEG block co-polymer. *International Journal of Polymeric Materials and Polymeric Biomaterials*, 1-14.
Kalita, M., Payne, M. M., & Bossmann, S. H. (2022). Glyco-nanotechnology: A biomedical perspective. *Nanomedicine: Nanotechnology, Biology and Medicine*, *42*, 102542.
Kang, B., Mackey, M. A., & El-Sayed, M. A. (2010). Nuclear targeting of gold nanoparticles in cancer cells induces DNA damage, causing cytokinesis arrest and apoptosis. *Journal of the American Chemical Society*, *132*(5), 1517-1519.
Karnik, R., Hong, S., Zhang, H., Mei, Y., Anderson, D. G., Karp, J. M., & Langer, R. (2008). Nanomechanical control of cell rolling in two dimensions through surface patterning of receptors. *Nano letters*, *8*(4), 1153-1158.
Khan, H., Mirzaei, H. R., Amiri, A., Kupeli Akkol, E., Ashhad Halimi, S. M., & Mirzaei, H. (2021). Glyco-nanoparticles: New drug delivery systems in cancer therapy. *Seminars in Cancer Biology*, *69*, 24-42. https://doi.org/https://doi.org/10.1016/j.semcancer.2019.12.004
Kheraldine, H., Rachid, O., Habib, A. M., Al Moustafa, A.-E., Benter, I. F., & Akhtar, S. (2021). Emerging innate biological properties of nano-drug delivery systems: A focus on PAMAM dendrimers and their clinical potential. *Advanced Drug Delivery Reviews*, *178*, 113908.

Kozielski, K. L., Ruiz-Valls, A., Tzeng, S. Y., Guerrero-Cázares, H., Rui, Y., Li, Y., Vaughan, H. J., Gionet-Gonzales, M., Vantucci, C., & Kim, J. (2019). Cancer-selective nanoparticles for combinatorial siRNA delivery to primary human GBM in vitro and in vivo. *Biomaterials*, *209*, 79-87.

Kumar, J., Basak, S., Kalkal, A., & Packirisamy, G. (2022). Recent advances in nanotechnology and microfluidic-based approaches for isolation and detection of circulating tumor cells (CTCs). *Nano-Structures & Nano-Objects*, *31*, 100886.

Kundu, S., Ghosh, M., & Sarkar, N. (2021). State of the art and perspectives on the biofunctionalization of fluorescent metal nanoclusters and carbon quantum dots for targeted imaging and drug delivery. *Langmuir*, *37*(31), 9281-9301.

Leake, M. C., & Quinn, S. D. (2023). A guide to small fluorescent probes for single-molecule biophysics. *Chemical Physics Reviews*, *4*(1).

Lee, H., Sun, E., Ham, D., & Weissleder, R. (2008). Chip–NMR biosensor for detection and molecular analysis of cells. *Nature medicine*, *14*(8), 869-874.

Lee, S. E., Liu, G. L., Kim, F., & Lee, L. P. (2009). Remote optical switch for localized and selective control of gene interference. *Nano letters*, *9*(2), 562-570.

Li, C., Yang, S., Li, R., Gong, S., Huang, M., Sun, Y., Xiong, G., Wu, D., Ji, M., & Chen, Y. (2022). Dual-aptamer-targeted immunomagnetic nanoparticles to accurately explore the correlations between circulating tumor cells and gastric cancer. *ACS Applied Materials & Interfaces*, *14*(6), 7646-7658.

Li, J. (2023). Probing the interactions of guanine on silver nanoparticles by surface-enhanced Raman spectroscopy on an electrochemical system. *Spectroscopy Letters*, *56*(1), 42-50.

Li, J., Deng, B., & Ye, J. (2023). Fluorescence-free bis (dithiolene) nickel dyes for surface-enhanced resonance Raman imaging in the second near-infrared window. *Biomaterials*, 122211.

Li, S., Zhang, Y., Ho, S.-H., Li, B., Wang, M., Deng, X., Yang, N., Liu, G., Lu, Z., & Xu, J. (2020). Combination of tumour-infarction therapy and chemotherapy via the co-delivery of doxorubicin and thrombin encapsulated in tumour-targeted nanoparticles. *Nature Biomedical Engineering*, *4*(7), 732-742.

Liang, Z., Wang, Q., Liao, H., Zhao, M., Lee, J., Yang, C., Li, F., & Ling, D. (2021). Artificially engineered antiferromagnetic nanoprobes for ultra-sensitive histopathological level magnetic resonance imaging. *Nature Communications*, *12*(1), 3840.

Liu, H., Sun, R., Wang, L., Chen, X., Li, G., Cheng, Y., Zhai, G., Bay, B.-H., Yang, F., & Gu, N. (2022). Biocompatible Iron Oxide Nanoring-Labeled Mesenchymal Stem Cells: An Innovative Magnetothermal Approach for Cell Tracking and Targeted Stroke Therapy. *ACS nano*, *16*(11), 18806-18821.

Lomakin, Y. A., Kaminskaya, A. N., Stepanov, A. V., Shmidt, A. A., Gabibov, A. G., & Belogurov Jr, A. A. (2019). Probing surface membrane receptors using engineered bacteriophage bioconjugates. *Bioconjugate Chemistry*, *30*(5), 1500-1506.

Lombardo, D., Calandra, P., Pasqua, L., & Magazù, S. (2020). Self-assembly of organic nanomaterials and biomaterials: The bottom-up approach for functional nanostructures formation and advanced applications. *Materials*, *13*(5), 1048.

Lunov, O., Uzhytchak, M., Smolková, B., Lunova, M., Jirsa, M., Dempsey, N. M., Dias, A. L., Bonfim, M., Hof, M., Jurkiewicz, P., Petrenko, Y., Kubinová, Š., & Dejneka, A. (2019). Remote Actuation of Apoptosis in Liver Cancer Cells via Magneto-Mechanical Modulation of Iron Oxide Nanoparticles. *Cancers*, *11*(12), 1873. https://www.mdpi.com/2072-6694/11/12/1873

Marrache, S., & Dhar, S. (2012). Engineering of blended nanoparticle platform for delivery of mitochondria-acting therapeutics. *Proceedings of the National Academy of Sciences*, *109*(40), 16288-16293.

Mignani, S., Shi, X., Ceña, V., & Majoral, J.-P. (2020). Dendrimer–and polymeric nanoparticle–aptamer bioconjugates as nonviral delivery systems: A new approach in medicine. *Drug Discovery Today*, *25*(6), 1065-1073.

Mishra, M. (2022). Latest Trends in Bioimaging Using Quantum Dots. *Smart Nanodevices for Point-of-Care Applications*, 135-142.

Misra, S. K., Rosenholm, J. M., & Pathak, K. (2023). Functionalized and Nonfunctionalized Nanosystems for Mitochondrial Drug Delivery with Metallic Nanoparticles. *Molecules*, *28*(12), 4701.

Mukherjee, S., Mukherjee, S., Abourehab, M. A., Sahebkar, A., & Kesharwani, P. (2022). Exploring dendrimer-based drug delivery systems and their potential applications in cancer immunotherapy. *European Polymer Journal*, 111471.

Myung, J. H., Gajjar, K. A., Saric, J., Eddington, D. T., & Hong, S. (2011). Dendrimer-mediated multivalent binding for the enhanced capture of tumor cells. *Angewandte Chemie International Edition*, *50*(49), 11769-11772.

Nadaroglu, H., Alayli, A., & Ince, S. (2017). Synthesis of Nanoparticles by Green Synthesis Method. *International Journal of Innovative Research and Reviews*, *1*, 6-9.

Nam, J.-M., Thaxton, C. S., & Mirkin, C. A. (2020). Nanoparticle-Based Bio-Barcodes for the Ultrasensitive Detection of Proteins. In *Spherical Nucleic Acids* (pp. 1479-1487). Jenny Stanford Publishing.

Nanou, A., Zeune, L. L., & Terstappen, L. W. (2019). Leukocyte-derived extracellular vesicles in blood with and without EpCAM enrichment. *Cells*, *8*(8), 937.

Nishio, N., van den Berg, N. S., Martin, B. A., van Keulen, S., Fakurnejad, S., Rosenthal, E. L., & Wilson, K. E. (2021). Photoacoustic molecular imaging for the identification of lymph node metastasis in head and neck cancer using an anti-EGFR antibody–dye conjugate. *Journal of Nuclear Medicine*, *62*(5), 648-655.

O'Brien, S. G., Guilhot, F., Larson, R. A., Gathmann, I., Baccarani, M., Cervantes, F., Cornelissen, J. J., Fischer, T., Hochhaus, A., & Hughes, T. (2003). Imatinib compared with interferon and low-dose cytarabine for newly diagnosed chronic-phase chronic myeloid leukemia. *New England Journal of Medicine*, *348*(11), 994-1004.

Osterfeld, S. J., Yu, H., Gaster, R. S., Caramuta, S., Xu, L., Han, S.-J., Hall, D. A., Wilson, R. J., Sun, S., & White, R. L. (2008). Multiplex protein assays based on real-time magnetic nanotag sensing. *Proceedings of the National Academy of Sciences*, *105*(52), 20637-20640.

Pal, A. K., Chandra, G. K., Umapathy, S., & Bharathi Mohan, D. (2020). Ultra-sensitive, reusable, and superhydrophobic Ag/ZnO/Ag 3D hybrid surface enhanced Raman scattering substrate for hemoglobin detection. *Journal of Applied Physics*, *127*(16).

Pan, Y., Du, X., Zhao, F., & Xu, B. (2012). Magnetic nanoparticles for the manipulation of proteins and cells. *Chemical Society Reviews*, *41*(7), 2912-2942.

Panagi, M., Voutouri, C., Mpekris, F., Papageorgis, P., Martin, M. R., Martin, J. D., Demetriou, P., Pierides, C., Polydorou, C., & Stylianou, A. (2020). TGF-β inhibition combined with cytotoxic nanomedicine normalizes triple negative breast cancer microenvironment towards anti-tumor immunity. *Theranostics*, *10*(4), 1910.

Patel, N. R., Hatziantoniou, S., Georgopoulos, A., Demetzos, C., Torchilin, V. P., Weissig, V., & D'Souza, G. G. (2010). Mitochondria-targeted liposomes improve the apoptotic and cytotoxic action of sclareol. *Journal of liposome research*, *20*(3), 244-249.

Piktel, E., Suprewicz, Ł., Depciuch, J., Chmielewska, S., Skłodowski, K., Daniluk, T., Król, G., Kołat-Brodecka, P., Bijak, P., & Pajor-Świerzy, A. (2021). Varied-shaped gold nanoparticles with nanogram killing efficiency as potential antimicrobial surface coatings for the medical devices. *Scientific reports*, *11*(1), 12546.

Pouton, C. W., Wagstaff, K. M., Roth, D. M., Moseley, G. W., & Jans, D. A. (2007). Targeted delivery to the nucleus. *Advanced Drug Delivery Reviews*, *59*(8), 698-717.

Qian, X.-M., & Nie, S. M. (2008). Single-molecule and single-nanoparticle SERS: from fundamental mechanisms to biomedical applications. *Chemical Society Reviews*, *37*(5), 912-920.

Quintela, I. A., de Los Reyes, B. G., Lin, C.-S., & Wu, V. C. (2019). Simultaneous colorimetric detection of a variety of Salmonella spp. in food and environmental samples by optical biosensing using oligonucleotide-gold nanoparticles. *Frontiers in microbiology*, *10*, 1138.

Rani, V., Venkatesan, J., & Prabhu, A. (2022). Liposomes-A promising strategy for drug delivery in anticancer applications. *Journal of Drug Delivery Science and Technology*, 103739.

Romond, E. H., Perez, E. A., Bryant, J., Suman, V. J., Geyer Jr, C. E., Davidson, N. E., Tan-Chiu, E., Martino, S., Paik, S., & Kaufman, P. A. (2005). Trastuzumab plus adjuvant chemotherapy for operable HER2-positive breast cancer. *New England Journal of Medicine*, *353*(16), 1673-1684.

Santana, J. G., Petukhova-Greenstein, A., Gross, M., Hyder, F., Pekurovsky, V., Gottwald, L. A., Boustani, A., Walsh, J. J., Kucukkaya, A. S., & Malpani, R. (2023). MR Imaging–Based In Vivo Macrophage Imaging to Monitor Immune Response after Radiofrequency Ablation of the Liver. *Journal of Vascular and Interventional Radiology*, *34*(3), 395-403. e395.

Schintke, S., & Frau, E. (2020). Modulated 3D cross-correlation dynamic light scattering applications for optical biosensing and time-dependent monitoring of nanoparticle-biofluid interactions. *Applied Sciences*, *10*(24), 8969.

Schwaminger, S. P., Fehn, S., Steegmüller, T., Rauwolf, S., Löwe, H., Pflüger-Grau, K., & Berensmeier, S. (2021). Immobilization of PETase enzymes on magnetic iron oxide nanoparticles for the decomposition of microplastic PET. *Nanoscale Advances*, *3*(15), 4395-4399.

Shakiba, S., Astete, C. E., Paudel, S., Sabliov, C. M., Rodrigues, D. F., & Louie, S. M. (2020). Emerging investigator series: polymeric nanocarriers for agricultural applications: synthesis, characterization, and environmental and biological interactions. *Environmental Science: Nano*, *7*(1), 37-67.

Shao, X., Meng, C., Song, W., Zhang, T., & Chen, Q. (2023). Subcellular Visualization: Organelle-Specific Targeted Drug Delivery and Discovery. *Advanced Drug Delivery Reviews*, 114977.

Shen, T., Weissleder, R., Papisov, M., Bogdanov Jr, A., & Brady, T. J. (1993). Monocrystalline iron oxide nanocompounds (MION): physicochemical properties. *Magnetic Resonance in Medicine*, *29*(5), 599-604.

Shen, Y., Lei, F., Meng, T., Li, C., Yang, Z., Huang, J., Song, F., & Wan, Y. (2021). Gold nanoparticles-mediated fluorescent chemical nose sensor for pathogenic diagnosis and phenotype. *Journal of Molecular Recognition*, *34*(11), e2919.

Shi, K., Song, C., Wang, Y., Chandrawati, R., & Lin, Y. (2023). Engineering receptor-mediated transmembrane signaling in artificial and living cells. *Communications Materials*, *4*(1), 65.

Shoji, S., Miura, S., Watanabe, S., Ohtsubo, A., Nozaki, K., Saida, Y., Ichikawa, K., Kondo, R., Tanaka, T., & Koyama, K. (2022). Phase II study of nanoparticle albumin-bound paclitaxel monotherapy for relapsed non-small cell lung cancer with patient-reported outcomes (NLCTG1302). *Translational Lung Cancer Research*, *11*(7), 1359.

Siddique, S., & Chow, J. C. (2020). Gold nanoparticles for drug delivery and cancer therapy. *Applied Sciences*, *10*(11), 3824.

Sonabend, A. M., Gould, A., Amidei, C., Ward, R., Schmidt, K. A., Zhang, D. Y., Gomez, C., Bebawy, J. F., Liu, B. P., & Bouchoux, G. (2023). Repeated blood–brain barrier opening with an implantable ultrasound device for delivery of albumin-bound paclitaxel in patients with recurrent glioblastoma: a phase 1 trial. *The Lancet Oncology*, *24*(5), 509-522.

Song, Y., Wu, Y., Xu, L., Jiang, T., Tang, C., & Yin, C. (2021). Caveolae-mediated endocytosis drives robust siRNA delivery of polymeric nanoparticles to macrophages. *ACS nano*, *15*(5), 8267-8282.

Souza, G. R., Molina, J. R., Raphael, R. M., Ozawa, M. G., Stark, D. J., Levin, C. S., Bronk, L. F., Ananta, J. S., Mandelin, J., & Georgescu, M.-M. (2010). Three-dimensional tissue culture based on magnetic cell levitation. *Nature nanotechnology*, *5*(4), 291-296.

Stanley, S. A., Gagner, J. E., Damanpour, S., Yoshida, M., Dordick, J. S., & Friedman, J. M. (2012). Radio-wave heating of iron oxide nanoparticles can regulate plasma glucose in mice. *Science*, *336*(6081), 604-608.

Sultana, J., & Sarma, D. (2020). Ag-catalyzed azide-alkyne cycloaddition: Copper free approaches for synthesis of 1, 4-disubstituted 1, 2, 3-triazoles. *Catalysis Reviews*, *62*(1), 96-117.

Sun, X., Shi, M., Zhang, C., Yuan, J., Yin, M., Du, S., Yu, S., Ouyang, B., Xue, F., & Yang, S.-T. (2021). Fluorescent ag–in–s/zns quantum dots for tumor drainage lymph node imaging in vivo. *ACS Applied Nano Materials*, *4*(2), 1029-1037.

Swierczewska, M., Liu, G., Lee, S., & Chen, X. (2012). High-sensitivity nanosensors for biomarker detection. *Chemical Society Reviews*, *41*(7), 2641-2655.

Tang, C., He, Z., Liu, H., Xu, Y., Huang, H., Yang, G., Xiao, Z., Li, S., Liu, H., & Deng, Y. (2020). Application of magnetic nanoparticles in nucleic acid detection. *Journal of Nanobiotechnology*, *18*(1), 1-19.

Thaxton, C. S., Elghanian, R., Thomas, A. D., Stoeva, S. I., Lee, J.-S., Smith, N. D., Schaeffer, A. J., Klocker, H., Horninger, W., & Bartsch, G. (2020). Nanoparticle-Based Bio-Barcode Assay Redefines "Undetectable" PSA and Biochemical Recurrence after Radical Prostatectomy. In *Spherical Nucleic Acids* (pp. 1489-1507). Jenny Stanford Publishing.

Tong, W. Y., Tan, W.-N., Azizi, M. A. K., Leong, C. R., El Azab, I. H., Lim, J. W., Mahmoud, M., Dailin, D. J., Ibrahim, M. M., & Chuah, L. F. (2023). Nanoparticle-laden contact lens for controlled release of vancomycin with enhanced antibiotic efficacy. *Chemosphere*, *338*, 139492.

Torchilin, V. P. (2005). Recent advances with liposomes as pharmaceutical carriers. *Nature reviews Drug discovery*, *4*(2), 145-160.

Tosat-Bitrián, C., & Palomo, V. (2020). CdSe quantum dots evaluation in primary cellular models or tissues derived from patients. *Nanomedicine: Nanotechnology, Biology and Medicine*, *30*, 102299.

Tu, J., Torrente-Rodríguez, R. M., Wang, M., & Gao, W. (2020). The era of digital health: A review of portable and wearable affinity biosensors. *Advanced Functional Materials*, *30*(29), 1906713.

Van de Walle, A., Perez, J. E., Abou-Hassan, A., Hémadi, M., Luciani, N., & Wilhelm, C. (2020). Magnetic nanoparticles in regenerative medicine: what of their fate and impact in stem cells? *Materials Today Nano*, *11*, 100084.

Vangijzegem, T., Lecomte, V., Ternad, I., Van Leuven, L., Muller, R. N., Stanicki, D., & Laurent, S. (2023). Superparamagnetic iron oxide nanoparticles (SPION): from fundamentals to state-of-the-art innovative applications for cancer therapy. *Pharmaceutics*, *15*(1), 236.

Vasir, J. K., & Labhasetwar, V. (2007). Biodegradable nanoparticles for cytosolic delivery of therapeutics. *Advanced Drug Delivery Reviews*, *59*(8), 718-728.

Veloso, S. R., Andrade, R. G., & Castanheira, E. M. (2021). Magnetoliposomes: Recent advances in the field of controlled drug delivery. *Expert Opinion on Drug Delivery*, *18*(10), 1323-1334.

Verma, P., Srivastava, A., Srikanth, C. V., & Bajaj, A. (2021). Nanoparticle-mediated gene therapy strategies for mitigating inflammatory bowel disease. *Biomaterials science*, *9*(5), 1481-1502.

Wan, Y., Wang, W., Lai, Q., Wu, M., & Feng, S. (2023). Advances in cell-penetrating poly (disulfide) s for intracellular delivery of therapeutics. *Drug Discovery Today*, 103668.

Wang, M., Liu, Y., Shao, B., Liu, X., Hu, Z., Wang, C., Li, H., Zhu, L., Li, P., & Yang, Y. (2022). HER2 status of CTCs by peptide-functionalized nanoparticles as the diagnostic biomarker of breast cancer and predicting the efficacy of anti-HER2 treatment. *Frontiers in Bioengineering and Biotechnology*, *10*, 1015295.

Wang, S., Peng, T., Meng, Q., Zhu, X., Guo, L., Yao, K., Wang, Z., Zheng, P., Ren, Z., & He, Z. (2020). Rapid and ultrasensitive detection of Salmonella typhimurium using a novel impedance biosensor based on SiO2@ MnO2 nanocomposites and interdigitated array microelectrodes. *Sensors and Actuators B: Chemical*, *324*, 128654.

Wang, S. X., & Li, G. (2008). Advances in giant magnetoresistance biosensors with magnetic nanoparticle tags: Review and outlook. *IEEE transactions on Magnetics*, *44*(7), 1687-1702.

Wilson Jr, R. E., O'Connor, R., Gallops, C. E., Kwizera, E. A., Noroozi, B., Morshed, B. I., Wang, Y., & Huang, X. (2020). Immunomagnetic capture and multiplexed surface marker detection of circulating tumor cells with magnetic multicolor surface-enhanced Raman scattering nanotags. *ACS Applied Materials & Interfaces*, *12*(42), 47220-47232.

Woźniak, M., Płoska, A., Siekierzycka, A., Dobrucki, L. W., Kalinowski, L., & Dobrucki, I. T. (2022). Molecular Imaging and Nanotechnology—Emerging Tools in Diagnostics and Therapy. *International journal of molecular sciences*, *23*(5), 2658.

Wu, S., Helal-Neto, E., Matos, A. P. d. S., Jafari, A., Kozempel, J., Silva, Y. J. d. A., Serrano-Larrea, C., Alves Junior, S., Ricci-Junior, E., & Alexis, F. (2020). Radioactive polymeric nanoparticles for biomedical application. *Drug Delivery*, *27*(1), 1544-1561.

Xia, N., Hunt, T. P., Mayers, B. T., Alsberg, E., Whitesides, G. M., Westervelt, R. M., & Ingber, D. E. (2006). Combined microfluidic-micromagnetic separation of living cells in continuous flow. *Biomedical microdevices*, *8*, 299-308.

Xianyu, Y., Dong, Y., Wang, Z., Xu, Z., Huang, R., & Chen, Y. (2019). Broad-range magnetic relaxation switching bioassays using click chemistry-mediated assembly of polystyrene beads and magnetic nanoparticles. *ACS sensors*, *4*(7), 1942-1949.

Xu, L., Wang, X., Wang, R., Liu, S., & Xu, M. (2023). Engineered Macrophages: A Safe-by-Design Approach for the Tumor Targeting Delivery of Sub-5 nm Gold Nanoparticles. *Small*, *19*(1), 2205474.

Xue, L., Deng, D., & Sun, J. (2019). Magnetoferritin: Process, prospects, and their biomedical applications. *International Journal of Molecular Sciences*, *20*(10), 2426.

Yamada, Y., & Harashima, H. (2008). Mitochondrial drug delivery systems for macromolecule and their therapeutic application to mitochondrial diseases. *Advanced Drug Delivery Reviews*, *60*(13-14), 1439-1462.

Yan, B., Thubagere, A., Premasiri, W. R., Ziegler, L. D., Dal Negro, L., & Reinhard, B. M. (2009). Engineered SERS substrates with multiscale signal enhancement: nanoparticle cluster arrays. *Acs Nano*, *3*(5), 1190-1202.

Yan, N., Tang, B. Z., & Wang, W.-X. (2021). Cell cycle control of nanoplastics internalization in phytoplankton. *ACS nano*, *15*(7), 12237-12248.

Yan, Y., Zhu, X., Yu, Y., Li, C., Zhang, Z., & Wang, F. (2022). Nanotechnology strategies for plant genetic engineering. *Advanced Materials*, *34*(7), 2106945.

Yang, C., & Merlin, D. (2019). Nanoparticle-mediated drug delivery systems for the treatment of IBD: current perspectives. *International Journal of Nanomedicine*, 8875-8889.

Yang, J. C., Haworth, L., Sherry, R. M., Hwu, P., Schwartzentruber, D. J., Topalian, S. L., Steinberg, S. M., Chen, H. X., & Rosenberg, S. A. (2003). A randomized trial of bevacizumab, an anti–vascular endothelial growth factor antibody, for metastatic renal cancer. *New England Journal of Medicine*, *349*(5), 427-434.

Yang, Y., Xu, B., Murray, J., Haverstick, J., Chen, X., Tripp, R. A., & Zhao, Y. (2022). Rapid and quantitative detection of respiratory viruses using surface-enhanced Raman spectroscopy and machine learning. *Biosensors and Bioelectronics*, *217*, 114721.

Yazdian, F. (2023). Aptamer-functionalized quantum dots for targeted cancer therapy. In *Aptamers Engineered Nanocarriers for Cancer Therapy* (pp. 295-315). Elsevier.

Yonezawa, S., Koide, H., & Asai, T. (2020). Recent advances in siRNA delivery mediated by lipid-based nanoparticles. *Advanced drug delivery reviews*, *154*, 64-78.
Yu, J. H., Steinberg, I., Davis, R. M., Malkovskiy, A. V., Zlitni, A., Radzyminski, R. K., Jung, K. O., Chung, D. T., Curet, L. D., & D'Souza, A. L. (2021). Noninvasive and highly multiplexed five-color tumor imaging of multicore near-infrared resonant surface-enhanced Raman nanoparticles in vivo. *Acs Nano*, *15*(12), 19956-19969.
Yuan, S., Xu, J., Zhou, B., Zhou, Y., Lang, M., Cao, J., Liu, Z., Yang, S., Gao, S., & Hao, J. (2022). SOX8 Affects Tumoral SPARC Expression by Regulating EZH2 to Attenuate Effectiveness of albumin-bound paclitaxel in PDAC. *International Journal of Biological Sciences*, *18*(3), 911.
Zare, S., Mehrabani, D., Jalli, R., Saeedi Moghadam, M., Manafi, N., Mehrabani, G., Jamhiri, I., & Ahadian, S. (2019). MRI-tracking of dental pulp stem cells in vitro and in vivo using dextran-coated superparamagnetic iron oxide nanoparticles. *Journal of clinical medicine*, *8*(9), 1418.
Zhang, D., Carr, D. J., & Alocilja, E. C. (2009). Fluorescent bio-barcode DNA assay for the detection of Salmonella enterica serovar Enteritidis. *Biosensors and Bioelectronics*, *24*(5), 1377-1381.
Zhang, H., Lin, X., Huang, Y., Wang, M., Cen, C., Tang, S., Dique, M. R., Cai, L., Luis, M. A., & Smollar, J. (2021). Detection methods and clinical applications of circulating tumor cells in breast cancer. *Frontiers in oncology*, *11*, 652253.
Zhang, X., Pan, J., Yao, M., Mendes, L. P., Sarisozen, C., Mao, S., & Torchilin, V. P. (2020). Charge reversible hyaluronic acid-modified dendrimer-based nanoparticles for siMDR-1 and doxorubicin co-delivery. *European Journal of Pharmaceutics and Biopharmaceutics*, *154*, 43-49.
Zhang, Z., Weng, Z., Yao, J., Liu, D., Zhang, L., Zhang, L., & Xie, G. (2022). Toehold-mediated nonenzymatic DNA strand displacement coupling UDG mediated PCR and multi-code magnetic beads for DNA genotyping. *Microchemical Journal*, *178*, 107340.
Zhu, C., Jiang, J., Jia, Y., Xu, Z. P., & Zhang, L. (2023). Beyond Drug Delivery System: Immunomodulatory Layered Double Hydroxide Nanoadjuvants Take an Essential Step Forward in Cancer Immunotherapy. *Accounts of Materials Research*.

BÖLÜM 6

Nanopartiküllerin İlaç Salım Sistemlerinde Kullanımı

Faysal SELİMOĞLU[1]

GİRİŞ

Hastalığı tedavi edebilir yeni ve etkili ilaçların üretilmesi, karmaşık olduğu gibi zor süreçleri barındırır. Oldukça kompleks ve ileri düzeyde teknoloji gerektiren bu adımlar hedef belirleme, biyokimyasal yapı analizi, hedefe etki mekanizmasının incelenmesi, farklı aşamalardaki (laboratuvar ve hayvan) deneylerle iyileştirme, klinik denemeler ve onay aşamalarını içerir. Bu manada ilaç kullanılarak gerçekleştirilen, tanı, tedavi ve görüntüleme gibi tedavinin her evresini kapsayan kapsayan ilaç salım sistemlerinin işlevselliğini artırmak ciddi bir önceliktir. İlaç salım sistemi, ilacın vücut sıvı kompartmanları arasındaki dağılımını, stabil halde istenilen hedef noktaya ulaşıp ulaşmadığı, tasarlanan ilaç ve devamındaki tedavi sürecinin başarı şansını direkt belirler. Bu itibarla nanoboyutlardaki maddelerin, ilaç salım sistemlerinde kullanılması çok büyük avantaj ve fark ortaya çıkarır.

Küçük boyutlu yapılar ilaç etken maddesinin vücutta dağılmasını kolaylaştırır. Hedef hücrelere ulaşabilme yeteneği artar. Böylece tedavi daha etkili hale gelir. İlaç tasarımında nano boyutlu malzeme kullanımı büyük bir fırsat sunar.

Teknolojinin sunduğu üstün avantajlar eşliğinde bu atomik boyutta müdahale imkanı sunun bu yapıların ilaç salım sistemlerinin tesirini zirveye çıkarmak adına hasta yararına önem taşıdığı yatsınamaz bir gerçektir.

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Kaynaklar

Alavi, M., & Hamidi, M. (2019). Passive and active targeting in cancer therapy by liposomes and lipid nanoparticles. Drug metabolism and personalized therapy, 34(1), 20180032.

Alavi, M., Karimi, N., & Safaei, M. (2017). Application of various types of liposomes in drug delivery systems. Advanced pharmaceutical bulletin, 7(1), 3.

Allen, T. M., & Cullis, P. R. (2013). Liposomal drug delivery systems: from concept to clinical applications. Advanced drug delivery reviews, 65(1), 36-48.

Ambrogio, M. W., Frasconi, M., Yilmaz, M. D., & Chen, X. (2013). New methods for improved characterization of silica nanoparticle-based drug delivery systems. Langmuir, 29(49), 15386-15393.

Animesh, K., Afrasim, M., R Bommareddy, R., Ayaz, A., Shruthi, R., & G Shivakumar, H. (2012). Applicability and approaches of (Meth) acrylate copolymers (Eudragits) in novel drug delivery systems. Current Drug Therapy, 7(4), 219-234.

Behbudi, G. (2020). Mini review of Graphene Oxide for medical detection and applications. Advances in Applied NanoBio-Technologies, 1(3), 63-66.

Betageri, G. V., & Parsons, D. L. (1992). Drug encapsulation and release from multilamellar and unilamellar liposomes. International journal of pharmaceutics, 81(2-3), 235-241.

Bhardwaj, A. K., Kant, A., Rehalia, A., Singh, V., & Sharma, R. (2023). A review on nanomaterials for drug delivery systems and application of carbon-based nanomaterials. ES Materials & Manufacturing, 21, 824.

Chandrakala, V., Aruna, V., & Angajala, G. (2022). Review on metal nanoparticles as nanocarriers: Current challenges and perspectives in drug delivery systems. *Emergent Materials*, *5*(6), 1593-1615.

Chandrakala, V., Aruna, V., & Angajala, G. (2022). Review on metal nanoparticles as nanocarriers: Current challenges and perspectives in drug delivery systems. Emergent Materials, 5(6), 1593-1615.

Chauhan, A. S. (2018). Dendrimers for drug delivery. Molecules, 23(4), 938.

Chen, S., Huang, S., Li, Y., & Zhou, C. (2021). Recent advances in epsilon-poly-L-lysine and L-lysine-based dendrimer synthesis, modification, and biomedical applications. Frontiers in Chemistry, 9, 659304.

Cosco, D., Paolino, D., Maiuolo, J., Russo, D., & Fresta, M. (2011). Liposomes as multicompartmental carriers for multidrug delivery in anticancer chemotherapy. Drug delivery and translational research, 1, 66-75.

Das, A., Ghosh, S., Ringu, T., & Pramanik, N. (2023). A Focus on Biomaterials Based on Calcium Phosphate Nanoparticles: An Indispensable Tool for Emerging Biomedical Applications. BioNanoScience, 13(2), 795-818.

Denieva, Z. G., Koloskova, O. O., Gileva, A. M., Budanova, U. A., & Sebyakin, Y. L. (2023). Mixed Cationic Liposomes Based on L-Amino Acids as Efficient Delivery Systems of Therapeutic Molecules into Cells. Biochemistry (Moscow), Supplement Series A: Membrane and Cell Biology, 17(2), 136-147.

Derycke, A. S., & de Witte, P. A. (2004). Liposomes for photodynamic therapy. Advanced drug delivery reviews, 56(1), 17-30.

Deshmukh, R., Prajapati, M., & Harwansh, R. K. (2023). Recent advances and prospects in naringin nanocarrier drug delivery system for cancer management. Journal of Drug Delivery Science and Technology, 105182.

Elzoghby, A. O., Samy, W. M., & Elgindy, N. A. (2012). Albumin-based nanoparticles as potential controlled release drug delivery systems. Journal of controlled release, 157(2), 168-182.

Esim, O., & Hascicek, C. (2021). Albumin-based nanoparticles as promising drug delivery systems for cancer treatment. Current Pharmaceutical Analysis, 17(3), 346-359.

Gao, J., Karp, J. M., Langer, R., & Joshi, N. (2023). The future of drug delivery. Chemistry of Materials, 35(2), 359-363.

Gidwani, B., Namdeo, P., Tiwari, S., Tripathi, A., Pandey, R. K., Shukla, S. S., & Vyas, A. (2022). Lipoidal Carrier as Drug Delivery System. Nanoparticles and Nanocarriers Based Pharmaceutical Formulations, 273.

Giles, M., Reynales, L., Jayaraman, A., Kaplan, O., Verma, K., Wiest, K., & McCarty, D. (2024). Usability and feasibility of a take-home methadone web-application for opioid treatment program patients: A Small Business Innovation Research mixed methods study. Journal of Substance Use and Addiction Treatment, 157, 209181.

Graham, S. M., Carlisle, R., Choi, J. J., Stevenson, M., Shah, A. R., Myers, R. S., & Coussios, C. C. (2014). Inertial cavitation to non-invasively trigger and monitor intratumoral release of drug from intravenously delivered liposomes. Journal of Controlled Release, 178, 101-107.

Hajebi, S., Yousefiasl, S., Rahimmanesh, I., Dahim, A., Ahmadi, S., Kadumudi, F. B., ... & Makvandi, P. (2022). Genetically Engineered Viral Vectors and Organic-Based Non-Viral Nanocarriers for Drug Delivery Applications. Advanced healthcare materials, 11(20), 2201583.

He, Q., & Shi, J. (2011). Mesoporous silica nanoparticle based nano drug delivery systems: synthesis, controlled drug release and delivery, pharmacokinetics and biocompatibility. Journal of Materials Chemistry, 21(16), 5845-5855.

Indulatha, V. N. (2023). Chapter-3 Novel Facilitation and Development in New Drug Dosage Forms for the Modern Pharmacotherapeutical Aspect. Advances in Chemical Sciences, 51.

Jan, M. S., Alam, W., & Shabnam, M. (2023). Fundamentals Applications of Controlled Release Drug Delivery.

Kaur, H., & Kaur, G. (2023). A Review on Past and Future Aspects of Silica in Drug Delivery and Sensing Applications. Advances in Diverse Applications of Polymer Composites: Synthesis, Application, and Characterization, 47.

Khatik, N., & Sachdeva, H. (2022). Graphite-based nanomaterials for drug delivery. Materials Today: Proceedings, 69, 30-35.

Khizar, S., Elkalla, E., Zine, N., Jaffrezic-Renault, N., Errachid, A., & Elaissari, A. (2023). Magnetic nanoparticles: Multifunctional tool for cancer therapy. Expert opinion on drug delivery, 20(2), 189-204.

Kumari, A., Yadav, S. K., & Yadav, S. C. (2010). Biodegradable polymeric nanoparticles-based drug delivery systems. Colloids and surfaces B: biointerfaces, 75(1), 1-18.

Li, J., Chen, X., Jiang, J., Zhao, L., & Xi, Z. (2023). Synthesis of Amphiphilic Block Polyphosphoester and Exploring Its Potential in Reduction-Responsive Drug Release. ACS Applied Polymer Materials.

Li, S., Chen, L., & Fu, Y. (2023). Nanotechnology-based ocular drug delivery systems: Recent advances and future prospects. Journal of Nanobiotechnology, 21(1), 232.

Li, Y., Li, N., Pan, W., Yu, Z., Yang, L., & Tang, B. (2017). Hollow mesoporous silica nanoparticles with tunable structures for controlled drug delivery. ACS applied materials & interfaces, 9(3), 2123-2129.

Li, Z., Wan, W., Bai, Z., Peng, B., Wang, X., Cui, L., & Tian, F. (2023). Construction of pH-responsive nanoplatform from stable magnetic nanoparticles for targeted drug delivery and intracellular imaging. Sensors and Actuators B: Chemical, 375, 132869.

Makadia, H. K., & Siegel, S. J. (2011). Poly lactic-co-glycolic acid (PLGA) as biodegradable controlled drug delivery carrier. Polymers, 3(3), 1377-1397.

Manasa, R., & Shivananjappa, M. (2023). Role of Nanotechnology-Based Materials in Drug Delivery. Advances in Novel Formulations for Drug Delivery, 279-307.

Martínez-López, A. L., Pangua, C., Reboredo, C., Campión, R., Morales-Gracia, J., & Irache, J. M. (2020). Protein-based nanoparticles for drug delivery purposes. International Journal of Pharmaceutics, 581, 119289.

Masoomzadeh, S., Gholikhani, T., Aminroaia, P., Taghvimi, A., & Javadzadeh, Y. (2023). How can Fullerenes Help in the Treatment of Diseases? A Review Article on Pharmaceutical Usage of Fullerenes as Carriers. Combinatorial Chemistry & High Throughput Screening, 26(15), 2607-2613.

Meirinho, S., Rodrigues, M., Santos, A. O., Falcão, A., & Alves, G. (2022). Self-emulsifying drug delivery systems: An alternative approach to improve brain bioavailability of poorly water-soluble drugs through intranasal administration. Pharmaceutics, 14(7), 1487.

Nair, A., Haponiuk, J. T., Thomas, S., & Gopi, S. (2020). Natural carbon-based quantum dots and their applications in drug delivery: A review. Biomedicine & Pharmacotherapy, 132, 110834.

Namata, F., Sanz del Olmo, N., Molina, N., & Malkoch, M. (2023). Synthesis and Characterization of Amino-Functional Polyester Dendrimers Based on Bis-MPA with Enhanced Hydrolytic Stability and Inherent Antibacterial Properties. Biomacromolecules, 24(2), 858-867.

Narmani, A., Kamali, M., Amini, B., Salimi, A., & Panahi, Y. (2018). Targeting delivery of oxaliplatin with smart PEG-modified PAMAM G4 to colorectal cell line: In vitro studies. Process Biochemistry, 69, 178-187.

Nightingale, J. M., & Spiller, R. (2023). Normal intestinal anatomy and physiology. In Intestinal Failure (pp. 13-33). Cham: Springer International Publishing.

Nori, Z. Z., Bahadori, M., Moghadam, M., Tangestaninejad, S., Mirkhani, V., Mohammadpoor-Baltork, I., & Alem, H. (2023). Synthesis and characterization of a new gold-coated magnetic nanoparticle decorated with a thiol-containing dendrimer for targeted drug delivery, hyperthermia treatment and enhancement of MRI contrast agent. Journal of Drug Delivery Science and Technology, 81, 104216.

Orekhova, A., Palocci, C., Chronopoulou, L., De Angelis, G., Badiali, C., Petruccelli, V., & Simonetti, G. (2022). Poly-(lactic-co-glycolic) Acid Nanoparticles Entrapping Pterostilbene for Targeting Aspergillus Section Nigri. Molecules, 27(17), 5424.

Pacheco, C., Baiao, A., Ding, T., Cui, W., & Sarmento, B. (2023). Recent advances in long-acting drug delivery systems for anticancer drug. Advanced Drug Delivery Reviews, 114724.

Paul, W., & Sharma, C. P. (2020). Inorganic nanoparticles for targeted drug delivery. Biointegration of medical implant materials, 333-373.

Perveen, M., Nazir, S., Arshad, A. W., Khan, M. I., Shamim, M., Ayub, K., & Iqbal, J. (2020). Therapeutic potential of graphitic carbon nitride as a drug delivery system for cisplatin (anticancer drug): A DFT approach. Biophysical Chemistry, 267, 106461.

Rancan, F., Papakostas, D., Hadam, S., Hackbarth, S., Delair, T., Primard, C., & Vogt, A. (2009). Investigation of polylactic acid (PLA) nanoparticles as drug delivery systems for local dermatotherapy. Pharmaceutical research, 26, 2027-2036.

Riley, T., Stolnik, S., Heald, C. R., Xiong, C. D., Garnett, M. C., Illum, L., & Gellert, P. R. (2001). Physicochemical evaluation of nanoparticles assembled from Poly (lactic acid) – Poly (ethylene glycol) (PLA– PEG) block copolymers as drug delivery vehicles. Langmuir, 17(11), 3168-3174.

Shadmani, N., Gohari, S., Kadkhodamanesh, A., Ghaderinia, P., Hassani, M., & Sharifyrad, M. (2023). The synthesis and development of poly (ε-caprolactone) conjugated polyoxyethylene sorbitan oleate-based micelles for curcumin drug release: an in vitro study on breast cancer cells. RSC advances, 13(34), 23449-23460.

Shahbaz, A., Hussain, N., Basra, M. A. R., & Bilal, M. (2022). Polysaccharides-Based Nano-Hybrid Biomaterial Platforms for Tissue Engineering, Drug Delivery, and Food Packaging Applications. Starch-Stärke, 74(7-8), 2200023.

Shcharbin, D., Bryszewska, M., Mignani, S., Shi, X., & Majoral, J. P. (2020). Phosphorus dendrimers as powerful nanoplatforms for drug delivery, as fluorescent probes and for liposome interaction studies: A concise overview. European Journal of Medicinal Chemistry, 208, 112788.

Shen, K., Li, L. X., Li, H., Xue, Z., You, J., & Yan, Y. (2023). Multifunctional Mn0. 5Zn0. 5Fe2O4 Nanoparticle/PPy-PEG Structures for Synergistic Photo-Magnetic Hyperthermia Applications. ACS Applied Nano Materials, 6(19), 18571-18581.

Shi, D., Beasock, D., Fessler, A., Szebeni, J., Ljubimova, J. Y., Afonin, K. A., & Dobrovolskaia, M. A. (2022). To PEGylate or not to PEGylate: Immunological properties of nanomedicine's most popular component, polyethylene glycol and its alternatives. Advanced drug delivery reviews, 180, 114079.

Sievens-Figueroa, L., Bhakay, A., Jerez-Rozo, J. I., Pandya, N., Romañach, R. J., Michniak-Kohn, B., & Davé, R. N. (2012). Preparation and characterization of hydroxypropyl methyl cellulose films containing stable BCS Class II drug nanoparticles for pharmaceutical applications. International journal of pharmaceutics, 423(2), 496-508.

Singh, G., Chawla, P. A., Faruk, A., Chawla, V., & Kaur, A. (2023). Computational Design of Molecularly Imprinted Polymers in Drug Delivery Systems: A Comprehensive Review. *Current Drug Delivery*, *20*(1), 75-88.

Singh, J., & Nayak, P. (2023). pH-responsive polymers for drug delivery: Trends and opportunities. Journal of Polymer Science.

Singh, V., & Tiwari, M. (2010). Structure-processing-property relationship of poly (glycolic acid) for drug delivery systems 1: synthesis and catalysis. International Journal of Polymer Science, 2010.

Singh, V., Sahebkar, A., & Kesharwani, P. (2021). Poly (propylene imine) dendrimer as an emerging polymeric nanocarrier for anticancer drug and gene delivery. *European Polymer Journal*,*158*, 110683.

Sirisha, V. L., & D'Souza, J. S. (2016). Polysaccharide-based nanoparticles as drug delivery systems. Marine OMICS, 663-702.

Soumya, K., More, N., Choppadandi, M., Aishwarya, D. A., Singh, G., & Kapusetti, G. (2023). A comprehensive review on carbon quantum dots as an effective photosensitizer and drug delivery system for cancer treatment. Biomedical Technology, 4, 11-20.

Spizzirri, U. G., Hampel, S., Cirillo, G., Nicoletta, F. P., Hassan, A., Vittorio, O., & Iemma, F. (2013). Spherical gelatin/CNTs hybrid microgels as electro-responsive drug delivery systems. International journal of pharmaceutics, 448(1), 115-122.

Su, Y., Xie, Z., Kim, G. B., Dong, C., & Yang, J. (2015). Design strategies and applications of circulating cell-mediated drug delivery systems. ACS biomaterials science & engineering, 1(4), 201-217.

Szczyglewska, P., Feliczak-Guzik, A., & Nowak, I. (2023). Nanotechnology–General Aspects: A Chemical Reduction Approach to the Synthesis of Nanoparticles. Molecules, 28(13), 4932.

Tangboriboon, N. (2019). Carbon and carbon nanotube drug delivery and its characterization, properties, and applications. In Nanocarriers for drug delivery (pp. 451-467). Elsevier.

Tracy, T., Wu, L., Liu, X., Cheng, S., & Li, X. (2023). 3D printing: Innovative solutions for patients and pharmaceutical industry. International Journal of Pharmaceutics, 631, 122480.

Ünal, S. (2022) Akciğer Tümörlerine Yönelik Paklitaksel Yüklü Polikaprolakton Nanopartikülleri; Formülasyon, Kapsamli İn Vitro Karakterizasyon Ve Salim Kinetik Çalişmalari.

Veres, P. (2018) Synthesis of silica-gelatin hybrid aerogels and their application as drug delivery systems.

Verger, A., Dollo, G., Brandhonneur, N., Martinais, S., Cordier, S., Lang, K., & Kirakci, K. (2023). PEGylated poly (lactic-co-glycolic acid) nanoparticles doped with molybdenum-iodide nanoclusters as a promising photodynamic therapy agent against ovarian cancer. Materials Advances, 4(15), 3207-3214.

Villa, C. H., Anselmo, A. C., Mitragotri, S., & Muzykantov, V. (2016). Red blood cells: Supercarriers for drugs, biologicals, and nanoparticles and inspiration for advanced delivery systems. Advanced drug delivery reviews, 106, 88-103.

Wang, L., Zhou, B., Huang, S., Qu, M., Lin, Q., Gong, T., & Zhang, L. (2019). Novel fibronectin-targeted nano disc drug delivery system displayed superior efficacy against prostate cancer compared with nanospheres. Nano Research, 12, 2451-2459.

Wang, T. (2023, March). Multi-responsive polymer-coated hollow mesoporous silica nanoparticle-based drug delivery system for targeted cancer therapy. In Second International Conference on Biological Engineering and Medical Science (ICBioMed 2022) (Vol. 12611, pp. 435-440). SPIE.

Wen, H., Jung, H., & Li, X. (2015). Drug delivery approaches in addressing clinical pharmacology-related issues: opportunities and challenges. The AAPS journal, 17, 1327-1340.

Xiang, H., Zhao, W., Jiang, K., He, J., Chen, L., Cui, W., & Li, Y. (2024). Progress in regulating inflammatory biomaterials for intervertebral disc regeneration. Bioactive Materials, 33, 506-531.

Yadollahi, Z., Motiei, M., Kazantseva, N., Císař, J., & Sáha, P. (2023). Whey Protein Isolate-Chitosan Polyelectrolyte Nanoparticles as a Drug Delivery System. Molecules, 28(4), 1724.

Yeruva, A. R. (2023). Providing A Personalized Healthcare Service to The Patients Using AIOPs Monitoring. Eduvest-Journal of Universal Studies, 3(2), 327-334.

Yusuf, A., Almotairy, A. R. Z., Henidi, H., Alshehri, O. Y., & Aldughaim, M. S. (2023). Nanoparticles as Drug Delivery Systems: A Review of the implication of nanoparticles' physicochemical properties on responses in biological systems. Polymers, 15(7), 1596.

Zangabad, P. S., Karimi, M., Mehdizadeh, F., Malekzad, H., Ghasemi, A., Bahrami, S., & Hamblin, M. R. (2017). Nanocaged platforms: modification, drug delivery and nanotoxicity. Opening synthetic cages to release the tiger. Nanoscale, 9(4), 1356-1392.

Zhang, X., Ge, J., Xue, Y., Lei, B., Yan, D., Li, N., & Cai, R. (2015). Controlled Synthesis of Ultrathin Lanthanide Oxide Nanosheets and Their Promising pH-Controlled Anticancer Drug Delivery. Chemistry–A European Journal, 21(34), 11954-11960.

BÖLÜM 7

Nanopartiküllerin Tıbbi Mikrobiyolojide Kullanımı

İlker AKIN[1]

GİRİŞ

Tıbbi mikrobiyoloji, mikrobiyolojinin mikroorganizmaları ve bunların insan sağlığı üzerindeki etkilerini incelemeye odaklanan ve tıp alanındaki uygulamalarını içeren daldır. Özellikle enfeksiyon hastalıkların önlenmesi, teşhisi ve tedavisi konuları üzerine odaklanmaktadır. İnsan sağlığını tehdit edip hastalığa sebep olan ve tıbbi mikrobiyolojinin alanına giren mikroorganizmalar; bakteriler, mantarlar ve virüslerin neden olduğubulaşıcı hastalıklar dünya çapında ölümlerin önde gelen nedenidir ve sağlık hizmetleri ve sosyoekonomik kalkınma üzerinde küresel etki yapmaktadır. Bu nedenle yeni tanı ve tedavi stratejilerinin geliştirilmesi gerekmektedir. Son yıllarda nanoteknolojideki gelişmeler ışığında nanoyapıların mikroorganizmalarla etkileşimi tıbbi mikrobiyolojide nanopartikül kullanımı oldukça yaygınlaşmış ve hem teşhis hem de tedavi uygulamalarında avantajlar sunarak biyomedikal alanda devrim yapmıştır. Tıbbi mikrobiyolojide nanopartiküllerin tanı amacıyla kullanımında çeşitli cihazsal yöntemler kullanılarak da desteklenmesi gerekmektedir. Günümüzde kullanılan nanopartikül tabanlı; antijen tespiti, PCR, immünofluoresans, elektrokimyasal sensörler, antikor ve protein tanı testleri, lateral flow testleri, yüzey kaplama ve mikrofluidik cihazlar, spektroskopik uygulamalar gibi her biri farklı amaçlar için tasarlanmış tanı aracı bulunmaktadır. Bu bölümde nanopartiküllerin yaygın olarak görülen virüs, bakteri ve mantarlar enfeksiyonlarının tanısında kullanılması için yapılan literatüre kazandırılan yeni yaklaşımlara değinilmiştir.

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Tablo 7.5. Kısaltmalar tablosu *(DEVAMI)*	
mAbs: Monoklonal antikorlar	MERS-CoV: Orta Doğu solunum sendromu koronavirüsü
MIC; Minimum inhibitör konsantrasyonu	MFC: Minimum fungisit konsantrasyonu
QD: Kuantum noktacık	PCR: Polimeraz zincir reaksiyonu
PEG: Polyetilen glikol	RCA: Yuvarlanan daire amplifikasyonu
ROS: Reaktif oksijen türleri	SARS-CoV-2: Şiddetli akut solunum sendromu koronavirüs 2
S. aureus: Staphylococcus aureus	*S. typhimurium: Salmonella typhimurium*
SPR: Yüzey plazmon rezonansı	SERS: Yüzey güçlendirilmiş raman spekroskopisi
T-CSZ NP: Timetalik bakır oksit-selenyum-çinko oksit nanopartikül	VAN: Vanilin
Zika: Zika Virüsü	

Kaynaklar

Adegoke, O., Morita, M., Kato, T., Ito, M., Suzuki, T., & Park, E. Y. (2017). Localized surface plasmon resonance-mediated fluorescence signals in plasmonic nanoparticle-quantum dot hybrids for ultrasensitive Zika virus RNA detection via hairpin hybridization assays. Biosensors & Bioelectronics, 94, 513–522. https://doi.org/10.1016/j.bios.2017.03.046

Ageitos, J.M., Sánchez-Pérez, A., Calo-Mata, P., Villa, T.G. (2017). Antimicrobial peptides (AMPs): Ancient compounds that represent novel weapons in the fight against bacteria. Biochemical Pharmacology, 133, 117-138. https://doi.org/10.1016/j.bcp.2016.09.018

Alhogail, S., Suaifan, G. A. R. Y., and Zourob, M. (2016). Rapid colorimetric sensing platform for the detection of Listeria monocytogenes foodborne pathogen. B*iosensors and Bioelectronics*. 86, 1061–1066. https://doi.org/10.1016/j.bios.2016.07.043

Azie, N., Neofytos, D., Pfaller, M., Meier-Kriesche, H.U., Quan, S.P., Horn, D. (2012). The PATH (Prospective Antifungal Therapy) Alliance® registry and invasive fungal infections: update 2012. Diagnostic Microbiology and Infectious Disease, 73:293–300. http://dx.doi.org/10.1016/j.diagmicrobio.2012.06.012

Bai, Y., Cui, Y., Paoli, G. C., Shi, C., Wang, D., Zhou, M., et al. (2016). Synthesis of amino-rich silica-coated magnetic nanoparticles for the efficient capture of DNA for PCR. Colloids and Surfaces B: Biointerfaces, 145, 257–266. https://doi.org/10.1016/j.colsurfb.2016.05.003

Bao, Y.P., Wei, T.F., Lefebvre, P.A., An, H., He, L., Kunkel, G.T., and Muller, U.R. (2006). Detection of Protein Analytes via Nanoparticle-Based Bio Bar Code Technology. Analytical Chemistry, 78(6): 2055-2059. https://doi.org/10.1021/ac051798d

Barchiesi, F., Orsetti, E., Gesuita, R., Skrami, E., Manso, E., Group, C.S. (2016). Epidemiology, clinical characteristics, and outcome of candidemia in a tertiary referral center in Italy from 2010 to 2014. *Infection*, 44(2):205–213. https://doi.org/10.1007/s15010-015-0845-z

Bhatnagar, I., Mahato, K., Ealla, K.K.R., Asthana, A., Chandra, P. (2018). Chitosan stabilized gold nanoparticle mediated self-assembled gliP nanobiosensor for diagnosis of invasive aspergillosis. International Journal of Biological Macromolecules, 110, 449–456. https://doi.org/10.1016/j.ijbiomac.2017.08.140

Borsa, B. A., Tuna, B. G., Hernandez, F. J., Hernandez, L. I., Bayramoglu, G., Arica, M. Y., et al. (2016). Staphylococcus aureus detection in blood samples by silica nanoparticle-oligonucleotides conjugates. Biosensors and Bioelectronics. 86, 27–32. https://doi.org/10.1016/j.bios.2016.06.023

Brangel, P., Sobarzo, A., Parolo, C., Miller, B. S., Howes, P. D., Gelkop, S., Lutwama, J. J., Dye, J. M., McKendry, R. A., Lobel, L., & Stevens, M. M. (2018). A serological point-of-care test for the detection of IgG antibodies against Ebola virus in human survivors. ACS Nano, 12(1), 63–73. https://doi.org/10.1021/acsnano.7b07021

Brown, G.D., Denning, D.W., Levitz, S.M. (2012). Tackling human fungal infections. Science, 336:647. http://dx.doi.org/10.1126/science.1222236

Campoccia, D., Montanaro, L., Arciola C.R. (2013). A review of the biomaterials technologies for infection-resistant surfaces. Biomaterials, 34, 8533-8554. https://doi.org/10.1016/j.biomaterials.2013.07.089

Chand, R., & Neethirajan, S. (2017). Microfluidic platform integrated with graphene-gold nano-composite aptasensor for one-step detection of norovirus. Biosensors & Bioelectronics, 98, 47–53. https://doi.org/10.1016/j.bios.2017.06.026

Chen, S., Tang, F., Tang, L., Li, L. (2017). Synthesis of Cu-Nanoparticle Hydrogel with Self-Healing and Photothermal Properties. ACS Applied Materials Interfaces, 9, 20895-20903. https://doi.org/10.1021/acsami.7b04956

Chen, J., Andler, S.M., Goddard, J.M., Nugen, S.R., Rotello, V.M. (2017). Integrating recognition elements with nanomaterials for bacteria sensing. Chemical Society Reviews, 46(5): 1272-1283. https://doi.org/10.1039/c6cs00313c

Chisanga, M., Muhamadali, H., Ellis, D.I., Goodacre, R. (2019). Enhancing disease diagnosis: biomedical applications of surface-enhanced Raman scattering. Applied Sciences, *9*(6), 1163. https://doi.org/10.3390/app9061163.

Curry, T., Kopelman, R., Shilo, M., Popovtzer, R. (2014). Multifunctional Theranostic Gold Nanoparticles for Targeted CT Imaging and Photothermal Therapy. Contrast Media & Molecular Imaging, 9, 53– 61. https://doi.org/10.1002/cmmi.1563

Dai, X., Zhao, Y., Yu, Y., Chen, X., Wei, X., Zhang, X., Li, C. (2017). Single Continuous Near-Infrared Laser-Triggered Photodynamic and Photothermal Ablation of Antibiotic-Resistant Bacteria Using Effective Targeted Copper Sulfide Nanoclusters. ACS Applied Materials and Interfaces, 9 (36): 30470-30479. https://doi.org/10.1021/acsami.7b09638

Dal, T. (2023). Tıbbi Mikrobiyoloji. Akademisyen Yayınevi Kitabevi. ISBN:9786253992231, https://doi.org/10.37609/akya.2656

De Pauw, B., Walsh, T.J., Donnelly, J.P., Stevens, D.A., Edwards, J.E., Calandra, T., et al. (2008). Revised definitions of invasive fungal disease from the European organiza- tion for research and treatment of cancer/invasive fungal infections coop- erative group and the national Institute of allergy and infectious diseases mycoses study group (EORTC/MSG) C. Clinical Infectious Diseases, 46(12): 1813-1821. https://doi.org/10.1086/588660.

Dagenais, T.R., Keller, N.P. (2009). Pathogenesis of Aspergillus fumigatus in invasive aspergillosis. Clinical Microbiology Reviews, 22:447–465. http://dx.doi.org/10.1128/CMR.00055-08 37

Ding, X., Yuan, P., Gao, N., Zhu, H., Yang, Y., Xu, Q.H. (2017). Au-Ag core-shell nanoparticles for simultaneous bacterial imaging and synergistic antibacterial activity, Nanomedicine,13, 297-305. https://doi.org/10.1016/j.nano.2016.09.003

Dizaj, S.M., Lotfipour, F., Barzegar-Jalali, M., Zarrintan, M.H., Adibkia, K. (2014). Antimicrobial activity of the metals and metal oxide nanoparticles. Materials Science Engineering C, 44, 278-284. https://doi.org/10.1016/j.msec.2014.08.031

Dodemont, M., Mendonca, R.D., Nonhoff, C., Roisin, S. and Denis, O. (2014). Performance of the Verigene Gram-Negative Blood Culture Assay for Rapid Detection of Bacteria and

Resistance Determinants. Journal of Clinical Microbiology, 52(8):3085-3087. https://doi.org/10.1128/JCM.01099-14

Duval, R.E., Grare, M., Demore, B., (2019). Fight against Antimicrobial Resistance: We Always Need New Antibacterials but for Right Bacteria. Molecules, 24, 3152. https://doi.org/10.3390/molecules24173152

Elewski, B.E. (1998). Onychomycosis: pathogenesis, diagnosis, and management. Clinical Microbiology Reviews,11(3):415–29. https://doi.org/10.1128/cmr.11.3.415.

Echavarria, M., Robinson, CRTA. (2015). Taxonomy and classification of fungi. In: Manual of clinical microbiology. 11th ed. Washington DC: ASM Press; p. 1935-1943.

Ekinci, M. ve Özdemir, D.İ. (2021). Nanoteranostikler, Ankara Ecz. Fak. Derg. / J. Fac. Pharm. Ankara, 45(1): 131-155. https://doi.org/10.33483/jfpau.717067

Fraire, J.C., Perez, L.A., Coronado, E.A.(2012). Rational Design of Plasmonic Nanostructures for Biomolecular Detection: Interplay between Theory and Experiments. ACS Nano, 6: 3441– 3452. https://doi.org/10.1021/nn300474p

Fargašová, A., Balzerová, A., Prucek, R., Sedláková, M. H., Bogdanová, K., Gallo, J., et al. (2017). Detection of prosthetic joint infection based on magnetically assisted surface enhanced raman spectroscopy. Analytical Chemistry, 89, 6598–6607. https://doi.org/10.1021/acs.analchem.7b00759

Fredrickson, J., Zachara, J., Balkwill, D. et. al. (2004). Geomicrobiology of high-level nuclear waste-contaminated vadose sediments at the Hanford site, Washington state. *Applied and Environmental Microbiology, 70 (7): 4230-4241.* https://doi.org/10.1128/AEM.70.7.4230-4241.2004.

Giljohann, D.A., Seferos, D.S., Daniel, D.L., Massich, M.D., Patel, P.C. and Mirkin, C.A. (2010). Gold Nanoparticles for Biology and Medicine. Angewandte Chemie International Edition, 49, 3280-3294. https://doi.org/10.1002/anie.200904359

Güneri, C.Ö. (2023). Tıbbi Mikrobiyoloji. Bakterilerin tanımlanmasında kullanılan geleneksel yöntemler ve prosedürler (s. 155-175). Akademisyen Yayınevi Kitabevi. ISBN:9786253992231, https://doi.org/10.37609/akya.2656

Haleem, A., Javaid, M., Singh, R.P., Rab, S., Suman, R. (2023). Applications of nanotechnology in medical field: a brief review. Global Health Journal, 7(2): 70-77. https://doi.org/10.1016/j.glohj.2023.02.008

Hajipour, M.J., Fromm, K.M., Akbar Ashkarran, A., Jimenez de Aberasturi, D., Larramendi, I.R., Rojo, T., Serpooshan, V., Parak, W.J., Mahmoudi, M. (2012) Antibacterial properties of nanoparticles. Trends Biotechnology, 30, 499-511. https://doi.org/10.1016/j.tibtech.2012.06.004

Han, H.W., Hsu, M.M.L., Choi, J.S., Hsu, C.K., Hsieh, H.Y., Li, H.C., Chang, H.C., Chang, T.C. (2014). Rapid detection of dermatophytes and Candida albicans in onychomycosis specimens by an oligonucleotide array. BMC Infectious Diseases, 14(1):1. https://doi.org/10.1186/s12879-014-0581-5

Hao, L., Gu, H., Duan, N., Wu, S., Ma, X., Xia, Y., et al. (2017). A chemiluminescent aptasensor based on rolling circle amplification and Co2+/N-(aminobut3r1)-N-(ethylisolumino1) functional flowerlike gold nanoparticles for Salmonella typhimurium detection. Talanta 164, 275–282. https://doi.org/10.1016/j.talanta.2016.11.053

Hasan, N., Guo, Z., and Wu, H. F. (2016). Large protein analysis of Staphylococcus aureus and Escherichia coli by MALDI TOF mass spectrometry using amoxicillin functionalized magnetic nanoparticles. Analytical and Bioanalytical Chemistry. 408, 6269–6281. https://doi.org/10.1007/s00216-016-9730-6

Hashem, A.H., Al-Askar, A.A., Haponiuk, J., Abd-Elsalam, K.A., Hasanin, M.S. (2023). Biosynthesis, Characterization, and Antifungal Activity of Novel Trimetallic Copper Oxide-Selenium-Zinc Oxide Nanoparticles against Some Mucorales Fungi. Microorganisms, 11(6):1380. http://dx.doi.org/10.3390/microorganisms11061380

Hawksworth, D.L. and Lücking, R. (2017). Fungal diversity revisited: 2.2 to 3.8 million species. Microbiology Spectrum, 5(4),15. https://doi.org/10.1128/microbiolspec.FUNK-0052-2016

He, Y., Wang, M., Fan, E., Ouyang, H., Yue, H., Su, X., et al. (2017). Highly specific bacteriophage-affinity strategy for rapid separation and sensitive detection of viable pseudomonas aeruginosa. Analytical Chemistry, 89, 1916–1921. https://doi.org/10.1021/acs.analchem.6b04389

Hoerr, V., Tuchscherr, L., Hüve, J., Nippe, N., Loser, K., Glyvuk, N., et al. (2013). Bacteria tracking by in vivo magnetic resonance imaging. BMC Biology, 11:63. https://doi.org/10.1186/1741-7007-11-63

Houhoula, D., Papaparaskevas, J., Zatsou, K., Nikolaras, N., Malkawi, H. I., Mingeot-Leclercq, M. sP., et al. (2017). Magnetic nanoparticle-enhanced PCR for the detection and identification of Staphylococcus aureus and Salmonella enteritidis. Nature Microbiology. 40, 165–169. ISN 1121-7138.

Huang, P., Wang, H., Cao, Z., Jin, H., Chi, H., Zhao, J., Yu, B., Yan, F., Hu, X., Wu, F., Jiao, C., Hou, P., Xu, S., Zhao, Y.,Feng, N., Wang, J., Sun, W., Wang, T., Gao, Y., Yang, S., Xia, X. (2018). A Rapid and Specific Assay for the Detection of MERS-CoV. Frontiers in Microbiology. 9:1101. http://dx.doi.org/10.3389/fmicb.2018.01101

Hu, S., Kang, H., Gu, F., Wang, C., Cheng, S., Gong, W., Wang, L., Gu, B., Yang, Y., (2021). Rapid detection method for pathogenic Candida captured by magnetic nanoparticles and identified using SERS via AgNPs+. International Journal of Nanomedicine, 16:941e50. https://doi.org/10.2147/IJN.S285339.

Hu, J., Jiang, Y.Z., Wu, L.L., Wu, Z., Bi, Y., Wong, G., Qiu, X., Chen, J., Pang, D. W., & Zhang, Z.L. (2017). Dual-signal readout nanospheres for rapid point-of-care detection of Ebola virus glycoprotein. Analytical Chemistry, 89(24), 13105–13111. https://doi.org/10.1021/acs.analchem.7b02222

Hu, Y., Huang, Y., Wang, Y., Li, C., Wong, W., Ye, X., & Sun, D. (2018). A photoelectrochemical immunosensor based on gold nanoparticles/ZnAgInS quaternary quantum dots for the high-performance determination of hepatitis B virus surface antigen. Analytica Chimica Acta, 1035, 136–145. https://doi.org/10.1016/j.aca.2018.06.019

Ibelli, T., Templeton, S., and Levi-Polyachenko, N. (2018). Progress on utilizing hyperthermia for mitigating bacterial infections. . International Journal of Hyperthermia, 34, 144–156. https://doi.org/10.1080/02656736.2017.1369173

Ishige, T., Honda, K., Shimizu, S. (2005). Whole organism biocatalysis. Current Opinion in Chemical Biology, 9 (2): 174-180. https://doi.org/10.1016/j.cbpa.2005.02.001

Jang, H., Hwang, E. Y., Kim, Y., Choo, J., Jeong, J., and Lim, D. W. (2016). Surface-enhanced raman scattering and fluorescence-based dual nanoprobes for multiplexed detection of bacterial pathogens. Journal of Biomedical Nanotechnology. 12, 1938–1951. https://doi.org/10.1166/jbn.2016.2309

Jung, Y.L., Jung, C., Parab, H., Li, T., Park, H.G. (2010). Direct Colorimetric Diagnosis of Pathogen Infections by Utilizing Thiol-Labeled PCR Primers and Unmodified Gold Nanoparticles. B*iosensors and Bioelectronics*, 25, 1941– 1946, https://doi.org/10.1016/j.bios.2010.01.010

Kell, A.J., Stewart, G., Ryan, S., Peytavi, R., Boissinot, M., Huletsky, A., et al. (2008). Vancomycin-modified nanoparticles for efficient targeting and preconcentration of Gram-positive and Gram-negative bacteria. Acs Nano, 2: 1777–1788. https://doi.org/10.1021/nn700183g

Kim, M.H., Yamayoshi, I., Mathew, S., Lin, H., Nayfach, J., and Simon, S.I. (2013). Magnetic nanoparticle targeted hyperthermia of cutaneous Staphylococcus aureus infection. Annals of Biomedical Engineering, 41, 598–609. https://doi.org/10.1007/s10439-012-0698-x

Kim, S. U., Jo, E. J., Mun, H., Noh, Y., and Kim, M. G. (2018). Ultrasensitive detection of escherichia coli o157:h7 by immunomagnetic separation and selective filtration with nitroblue tetrazolium/5-bromo-4- chloro-3-indolyl phosphate signal amplification. Journal of Agricultural and Food Chemistry, 66: 4941–4947. https://doi.org/10.1021/acs.jafc.8b00973

Kim, Y.T., Kim, K.H., Kang, E.S., Jo, G., Ahn, S.Y., Park, S.H., et al. (2016). Synergistic effect of detection and separation for pathogen using magnetic clusters. Bioconjugate Chemistry, 27, 59–65. https://doi.org/10.1021/acs.bioconjchem.5b00681

Kim, E.Y., Stanton, J., Korber, B.T. Krebs, K., Bogdan, D., Kunstman, K., Wu, S., Phair, J.P., Mirkin, C.A., Wolinsky, S.M. (2008). Detection of HIV-1 p24 Gag in plasma by a nanoparticle-based bio-barcode-amplification method. *Nanomedicine*, 3: 293-303. https://doi.org/10.2217/17435889.3.3.293

Kim, H., Park, M., Hwang, J., Kim, J.H., Chung, D.R., Lee, K.S. Kang, M. (2019). Development of Label Free Colorimetric Assay for MERS-CoV Using Gold Nanoparticles. ACS Sensor, 4, 1306– 1312, https://doi.org/10.1021/acssensors.9b00175

Kitching, M., Ramani, M., Marsili, E. (2015). Fungal biosynthesis of gold nanoparticles: mechanism and scale up. Microbial Biotechnology, 8(6): 904–917. https://doi.org/10.1111/1751-7915.12151.

Konopka, J.B., Casadevall, A., Taylor, J.W., Heitman, J., Cowen, L.(2019). One health: fungal pathogens of humans, animals and plants. American Academy of Microbiology Colloquia Reports. p. 1e3, Bookshelf ID: NBK549988. https://doi.org/10.1128/AAMCol.18Oct.2017

Köhler, J.R., Hube, B., Puccia, R., Casadevall, A., Perfect, J.R. (2017). Fungi that infect humans. Microbiology Spectrum, 5(3). https://doi.org/10.1128/microbiolspec.FUNK-0014-2016

Kuang, H., Cui, G., Chen, X., Yin, H., Yong, Q., Xu, L., et al. (2013). A one- step homogeneous sandwich immunosensor for Salmonella detection based on magnetic nanoparticles (MNPs) and quantum dots (QDs). International Journal of Molecular Sciences, 14, 8603–8610. https://doi.org/10.3390/ijms14048603

Kwon, D., Joo, J., Lee, J., Park, K. H., and Jeon, S. (2013). Magnetophoretic chromatography for the detection of pathogenic bacteria with the naked eye. Analytical Chemistry, 85, 7594–7598. https://doi.org/10.1021/ac401717f

Lau, I.P.M., Ngan, E.K., Loo, J.F., Suen, Y.K., Ho, H.P., Kong, S.K. (2010). Aptamer-based bio-barcode assay for the detection of cytochrome-*c* released from apoptotic cells. Biochemical and Biophysical Research Communication, 395(4): 560-564. https://doi.org/10.1016/j.bbrc.2010.04.066.

Li, Y., Zhang, W., Niu, J., Chen, Y. (2012). Mechanism of photogenerated reactive oxygen species and correlation with the antibacterial properties of engineered metal-oxide nanoparticles. ACS Nano, 6(6): 5164-5173. https://doi.org/10.1021/nn300934k

Li, Z., Yi, Y., Luo, X., Xiong, N., Liu, Y., Li, S., Sun, R., Wang, Y., Hu, B., Chen, W., Zhang, Y., Wang, J., Huang, B., Lin, Y., Yang, J., Cai, W., Wang, X., Cheng, J., Chen, Z., … Ye, F. (2020). Development and clinical application of a rapid IgM-IgG combined antibody test for SARS-CoV-2 infection diagnosis. Journal of Medical Virology, 92(9), 1518–1524. https://doi.org/10.1002/jmv.25727

Li, H., Li, C., Martin, F. L., and Zhang, D. (2017). Diagnose pathogens in drinking water via magnetic surface-enhanced raman scattering (SERS) assay. Materials Today: Proceedings, 4: 25–31. https://doi.org/10.1016/j.matpr.2017.01.189

Li, H., Rothberg, L. (2004). Colorimetric Detection of DNA Sequences Based on Electrostatic Interactions with Unmodified Gold Nanoparticles. Proceedings of the National Academy of Sciences of the United States of America, 101, 14036– 14039. https://doi.org/10.1073/pnas.040611510

Lionakis, M.S. and Netea, M.G. (2013). Candida and Host Determinants of Susceptibility to Invasive Candidiasis. *PLoS Pathogenes*, 9(1): e1003079. https://doi.org/10.1371/journal.ppat.1003079

Loo, J.F., Lau, P.M., Ho, H.P., Kong, S.K. (2013). An aptamer-based bio-barcode assay with isothermal recombinase polymerase amplification for cytochrome-*c* detection and anti-cancer drug screening. *Talanta*, 15(1): 159-165. https://doi.org/10.1016/j.talanta.2013.04.051

Martins, J.F.S., Castilho, M.L., Cardoso, M.A.G., Carreiro, A.P., Martin, A.A., Raniero, L. (2012). Identification of paracoccidioides brasiliensis by gold nanoprobes. In Proceedings of the Biomedical Vibrational Spectroscopy V: Advances in Research and Industry, San Francisco, CA, USA, 31 January 2012.

Meng, X., Li, F., Li, F., Xiong, Y., and Xu, H. (2017). Vancomycin modified PEGylated-magnetic nanoparticles combined with PCR for efficient enrichment and detection of Listeria monocytogenes. Sensors and Actuators B: Chemical, 247: 546–555. https://doi.org/10.1016/j.snb.2017.03.079

Mestas, J., Polanco, C.M., Felsenstein, S., Dien Bard, J. (2014). Performance of the Verigene Gram-Positive Blood Culture Assay for Direct Detection of Gram-Positive Organisms and Resistance Markers in a Pediatric Hospital. Journal of Clinical Microbiology, *52(1): 283-287*. https://doi.org/10.1128/JCM.02322-13

Misra, S.K., Dighe, K., Schwartz-Duval, A.S., Shang, Z., Labriola, L.T., Pan, D. (2018). In Situ Plasmonic Generation in Functional Ionic-Gold-Nanogel Scaffold for Rapid Quantitative Bio-Sensing. B*iosensors and Bioelectronics*, 120, 77– 84, https://doi.org/10.1016/j.bios.2018.08.019

Moitra, P., Alafeef, M., Alafeef, Dighe, K., Frieman, M.B., Pan, D. (2020). Selective naked-eye detection of SARS-CoV-2 mediated by N gene targeted antisense oligonucle-otide capped plasmonic nanoparticles. ACS Nano, 14: 7617–7627. https://doi.org/10.1021/acsnano.0c03822

Naja, G., Hrapovic, S., Male, K., Bouvrette, P., Luong, J.H.T. (2008). Rapid detection of microorganisms with nanoparticles and electron microscopy. Microscopy Research and Technique, 71, 742–748. https://doi.org/10.1002/jemt.20614

Nam, J.M., Thaxton, C.S. and Mirkin, C.A. (2003). Nanoparticle-Based Bio-Bar Codes for the Ultrasensitive Detection of Proteins. Science, 301(5641): 1884-1886. https://doi.org/10.1126/science.1088755

Nam, J.M., Jang, K.J. and Groves, J.T. (2007). Detection of proteins using a colorimetric bio-barcode assay. Natural Protocols, 2, 1438-1444. https://doi.org/10.1126/10.1038/nprot.2007.201

Nam, J.M., Wise, A.R. & Groves, J.T. (2005). Colorimetric bio-barcode amplification assay for cytokines. Analytical Chemistry, 77, 6985–6988. https://doi.org/10.1021/ac0513764

Nasimi, P. and Haidari, M. (2013). Medical Use of Nanoparticles: Drug Delivery and Diagnosis Diseases. International Journal of Green Nanotechnology, 1:1-5. https://doi.org/10.1177/1943089213506978

Nasrin, F., Chowdhury, A. D., Takemura, K., Kozaki, I., Honda, H., Adegoke, O., & Park, E. Y. (2020). Fluorometric virus detection platform using quantum dots-gold nanocomposites optimizing the linker length variation. Analytica Chimica Acta, 1109, 148–157. https://doi.org/10.1016/j.aca.2020.02.039

Neely, L.A., Audeh, M., Phung, N.A., Min, M., Suchocki, A., Plourde, D., Blanco, M., Demas, V., Skewis, L.R., Anagnostou, T., et al. (2013). T2 magnetic resonance enables nanoparticle-mediated rapid detection of candidemia in whole blood. Science Translational Medicine, 5(182): 182ra54. https://doi.org/10.1126/scitranslmed.3005377

Niemeyer, C.M., Adler, M. and Wacker, R. (2005). Immuno-PCR: high sensitivity detection of proteins by nucleic acid amplification. Trends Biotechnology, 23(4): 208-216. https://doi.org/10.1016/j.tibtech.2005.02.006

Oh, S., Kim, J., Tran, V. T., Lee, D. K., Ahmed, S. R., Hong, J. C., Lee, J., Park, E. Y., & Lee, J. (2018). Magnetic nanozyme-linked immunosorbent assay for ultrasensitive influenza a virus detection. ACS Applied Materials & Interfaces, 10(15), 12534–12543. https://doi.org/10.1021/acsnano.5b00240

Pan, D., Schirra, C.O., Wickline, S.A., Lanza, G.M. (2014). Multicolor Computed Tomographic Molecular Imaging with Noncrystalline High-Metal-Density Nanobeacons. Contrast Media Molecular Imaging, 9: 13-25. https://doi.org/10.1002/cmmi.1571(a)

Pan, D., Pramanik, M., Senpan, A., Yang, X., Song, K.H., Scott, M. J., Zhang, H., Gaffney, P.J., Wickline, S.A.,Wang, L.V., Lanza, G.M.(2009). Molecular Photo Acoustic Imaging (PAI) with Ligand-Directed Gold Nanobeacons. Angewandte Chemie International Edition, 48, 4170– 4173. https://doi.org/10.1002/anie.200805947(b)

Pan, D., Pramanik, M., Senpan, A., Ghosh, S., Wickline, S.A., Wang, L.V., Lanza, G.M. (2010). Near Infrared Photoacoustic Detection of Sentinel Lymphnodes with Gold Nanobeacons. Biomaterials, 31: 4088– 4093. https://doi.org/10.1016/j.biomaterials.2010.01.136(c)

Pan, D., Pramanik, M., Senpan, A., Wickline, S.A., Wang, L.V., Lanza, G.M. (2010). A Facile Synthesis of Novel Self-Assembled Gold Nanorods Designed for Near-Infrared Imaging. Journal of Nanoscience and Nanotechnology, 10, 8118– 8123, https://doi.org/10.1166/jnn.2010.3034(d)

Park, C., Lee, J., Kim, Y., Kim, J., Lee, J., and Park, S. (2017). 3D-printed microfluidic magnetic preconcentrator for the detection of bacterial pathogen using an ATP luminometer and antibody-conjugated magnetic nanoparticles. Journal of Microbiological Methods,132, 128–133. https://doi.org/10.1016/j.mimet.2016.12.001

Pei, F., Wang, P., Ma, E., Yang, Q., Yu, H., Gao, C., Li, Y., Liu, Q., & Dong, Y. (2019). A sandwich-type electrochemical immunosensor based on RhPt NDs/NH2-GS and Au NPs/PPy NS for quantitative detection hepatitis B surface antigen. Bioelectrochemistry, 126, 92–98. https://doi.org/10.1016/j.bioelechem.2018.11.008

Peng, L., Li, B.L., Zhou, C.W., Li, N.B., Setyawati, M.I., Zou, H.L.(2018). Naked-Eye Recognition: Emerging Gold Nano-Family for Visual Sensing. Applied Materials Today, 11, 166–188, https://doi.org/10.1016/j.apmt.2018.02.007

Penesyan, A., Gillings, M., Paulsen, I.T. (2015). Antibiotic discovery: Combatting bacterial resistance in cells and in biofilm communities. Molecules,20, 5286–5298. https://doi.org/10.3390/molecules20045286

Peter Donnelly, J., Chen, S.C., Kauffman, C.A., Steinbach, W.J., Baddley, J.W., Verweij, P.E., et al. (2020). Revision and update of the consensus definitions of invasive fungal disease from the european organization for research and treatment of cancer and the mycoses study group education and research consortium. Clinical Infectious Diseases, 71(6):1367-1376. https://doi.org/10.1093/cid/ciz1008.

Pfaller, M.A., Diekema, D.J. (2010). Epidemiology of invasive mycoses in North America. Critical Reviews in Microbiology, 36:1–53. http://dx.doi.org/10.3109/10408410903241444

Pickering JW, Sant HW, Bowles CA, Roberts WL, Woods GL. (2005). Evaluation of a (1→3)-β-D-glucan assay for diagnosis of invasive fungal infections. Journal of Clinical Microbiology, 43(12): 5957–62. https://doi.org/10.1128/jcm.43.12.5957-5962.2005

Raghupathi, K.R., Koodali, R.T., Manna, A.C. (2011). Size-dependent bacterial growth inhibition and mechanism of antibacterial activity of zinc oxide nanoparticles. Langmuir, 27(7): 4020-4028. https://doi.org/10.1021/la104825u

Rappé, M.S., Giovannoni, S.J. (2003). The uncultured microbial majority. *Annual Review of Microbiology, 57: 369- 394.* https://doi.org/10.1146/annurev.micro.57.030502.090759

Rigby, S., Procop, G.W., Haase, G., Wilson, D., Hall, G., Kurtzman, C., Oliveira, K., Von Oy, S., Hyldig-Nielsen, J.J., Coull, J., et al. (2002). Fluorescence in situ hybridization with peptide nucleic acid probes for rapid identification of Candida albicans directly from blood culture bottles. Journal of Clinical Microbiology, 40, 2182–2186. https://doi.org/10.1128/JCM.40.6.2182-2186.2002

Qiu, G., Gai, Z., Tao, Y., Schmitt, J., Kullak-Ublick, G. A., & Wang, J. (2020). Dual functional plasmonic photothermal biosensors for highly accurate severe acute respiratory syndrome coronavirus 2 detection. ACS Nano, 14(5), 5268–5277. https://doi.org/10.1021/acsnano.0c02439

Sears, C.L. (2005). A dynamic partnership: celebrating our gut flora. Anaerobe. 11 (5):247-251. https://doi.org/10.1016/j.anaerobe.2005.05.00

Shim, W.B., Song, J.E., Mun, H., Chung, D.H., and Kim, M.G. (2014). Rapid colorimetric detection of Salmonella typhimurium using a selective filtration technique combined with antibody-magnetic nanoparticle nanocomposites. Analytical and Bioanalytical Chemistry, 406, 859–866. https://doi.org/10.1007/s00216-013-7497-6

Shokri, E., Hosseini, M., Davari, M.D., Ganjali, M.R., Peppelenbosch, M. P., Rezaee, F.(2017). Disulfide-Induced Self-Assembled Targets. A Novel Strategy for the Label Free Colorimetric Detection of DNAs/RNAs via Unmodified Gold Nanoparticles. Scientific Reports, 7, 1 https://doi.org/10.1038/srep45837

Simon-Deckers, A., Loo, S., Mayne-L'hermite, M., Herlin-Boime, N., Menguy, N., Reynaud, C., Gouget, B., Carrière, M. (2009). Size, composition and shape-dependent toxicological impact of metal oxide nanoparticles and carbon nanotubes toward bacteria. Environmental Science and Technology. 43(21): 8423-8429. https://doi.org/10.1021/es9016975

Sojinrin, T., Conde, J., Liu, K., Curtin, J., Byrne, H.J., Cui, D., Tian, F. (2017). Plasmonic gold for detection of fungi and human cutaneous fungal infections. Analytical and Bioanalytical Chemistry, 409(19):4647-4658. https://doi.org/10.1007/s00216-017-0414-7.

Spengler, M., Adler, M., Niemeyer, C.M. (2015). Highly sensitive ligand-binding assays in pre-clinical and clinical applications: Immuno-PCR and other emerging techniques. Analyst, 140:6175–6194. http://dx.doi.org/10.1039/C5AN00822K.

Stajich, J.E., Kahmann, R., Boone, C., Denning, D.W., Gow, N.A.R., Klein, B.S., et al. (2020). Threats posed by the fungal kingdom to humans, Wildlife, and Agriculture. mBio,11(3):e00449-20. https://doi.org/10.1128/mBio.00449-20.

Steinmetz, M., Lima, D., Viana, A. G., Fujiwara, S. T., Pessoa, C. A., Etto, R. M., & Wohnrath, K. (2019). A sensitive label-free impedimetric DNA biosensor based on silsesquioxane-functionalized gold nanoparticles for Zika virus detection. Biosensors & Bioelectronics, 141, 111351. https://doi.org/10.1016/j.bios.2019.111351

Takemura, K., Adegoke, O., Takahashi, N., Kato, T., Li, T. C., Kitamoto, N., Tanaka, T., Suzuki, T., & Park, E. Y. (2017). Versatility of a localized surface plasmon resonance-based gold nanoparticle-alloyed quantum dot nanobiosensor for immunofluorescence detection of viruses. Biosensors & Bioelectronics, 89(Pt 2), 998–1005. https://doi.org/10.1016/j.bios.2016.10.045

Tang, Y., Zou, J., Ma, C., Ali, Z., Li, Z., Li, X., et al. (2013). Highly sensitive and rapid detection of Pseudomonas aeruginosa based on magnetic enrichment and magnetic separation. Theranostics, 3:85–92. https://doi.org/10.7150/thno.5588

Tang, S., Zhao, J., Storhoff, J.J., Norris, P.J., Little, R.F., Yarchoan, R., Stramer, S.L., Patno, T., Domanus, M., Dhar, A., Mirkin, C.A., Hewlett, I.K. (2007). Nanoparticle-Based Biobarcode Amplification Assay (BCA) for Sensitive and Early Detection of Human Immunodeficiency Type 1 Capsid (p24) Antigen. *Journal of Acquired Immune Deficiency Syndromes, 46:* 231-237. https://doi.org/10.1097/QAI.0b013e31814a554b

Tang, Y., Wang, H., Xiang, J., Chen, Y., He, W., Deng, N. and Yang, H. (2010). A sensitive immunosorbent bio-barcode assay combining PCR with icELISA for detection of gonyautoxin 2/3. Analytica Chimica Acta, 657: 210-214. https://doi.org/10.1016/j.aca.2009.10.045

Thaxton, C.S., Elghanian, R., Thomas, A.D., Stoeva, S.I., Lee, C.S., Smith, N.D., Schaeffer, A.C., Klocker, H., Horninger, W., Bartsch, G., Mirkin, C.A. (2009). Nanoparticle-based bio-barcode assay redefines"undetectable" PSA and biochemical recurrence after radical prostatectomy. The Proceedings of the National Academy of Sciences (PNAS), 106: 18437-18442. https://doi.org/10.1073/pnas.0904719106

Wang, J., Drelich, A.J., Hopkins, C.M., Mecozzi, S., Li, L., Kwon, G., Hong, S. (2022). Gold nanoparticles in virus detection: Recent advances and potential considerations for SARS-CoV-2 testing development. Wiley Interdisciplinary Reviews-Nanomedicine and Nanobiotechnology, 14(1): e1754. https://doi.org/10.1002/wnan.1754

Wang, C., Gu, B., Liu, Q., Pang, Y., Xiao, R., and Wang, S. (2018). Combined use of vancomycin-modified Ag-coated magnetic nanoparticles and secondary enhanced nanoparticles for rapid surface-enhanced Raman scattering detection of bacteria. International Journal of Nanomedicine. 13, 1159–1178. https://doi.org/10.2147/ijn.s150336

Whitman, W., Coleman, D., Wiebe, W. (1998). Prokaryotes: the unseen majority. *Proceedings of the National Academy of Sciences of the United States of America, 95 (12): 6578-6583.* https://doi.org/10.1073/pnas.95.12.6578.

Villamizar, R.A., Maroto, A., Rius, F.X. (2009). Improved detection of Candida albicans with carbon nanotube field-effect transistors. Sensors and Actuators B: Chemical, 136, 451–457. https://doi.org/10.1016/j.snb.2008.10.013

Yang, X., Zhou, X., Zhu, M., and Xing, D. (2017). Sensitive detection of Listeria monocytogenes based on highly efficient enrichment with vancomycin- conjugated brush-like magnetic nano-platforms. B*iosensors and Bioelectronics*. 91, 238–245. https://doi.org/10.1016/j.bios.2016.11.044

Yin, H.Q., Jia, M.X., Yang, S., Wang S.Q. and Zhang, Z.G. (2012). A nanoparticle-based bio-barcode assay for ultrasensitive detection of ricin toxin. *Toxicon*, 59:12-16. https://doi.org/10.1016/j.toxicon.2011.10.003

Yuan, P., Ding, X., Yang, Y.Y., Xu, Q.H. (2018). Metal Nanoparticles for Diagnosis and Therapy of Bacterial Infection. Advanced Healthcare Materials, 1701392, 1-17. https://doi.org/10.1002/adhm.201701392

Yuan, P., Ding, X., Guan, Z., Gao, N., Ma, R., Jiang, X.F., Yang, Y.Y., Xu, Q.H. (2015). Plasmon-Coupled Gold Nanospheres for Two-Photon Imaging and Photoantibacterial Activity. Advanced Healthcare Materials, 4(5): 674-678. https://doi.org/10.1002/adhm.201400524

Xiang, J., Yan, M., Li, H., Liu, T., Lin, C., Huang, S., Shen, C. (2020). Evaluation of Enzyme-Linked Immunoassay and Colloidal Gold-Immunochromatographic Assay Kit for Detection of Novel Coronavirus (SARS-Cov-2) Causing an Outbreak of Pneumonia (COVID-19) MedRxiv. https://doi.org/10.1101/2020.02.27.20028787.

Xiu, Z.M., Zhang, Q.B., Puppala, H.L., Colvin, V.L., Alvarez, P.J.J. (2012). Negligible particle-specific antibacterial activity of silver nanoparticles. Nano Letters, 12, 4271-4275. https://doi.org/10.1021/nl301934w

Xu, J. (2020). Fungal species concepts in the genomics era. Genome, 63(9):459-468. https://doi.org/10.1139/gen-2020-0022.

Xu, C., Akakuru, O.U., Zheng, J., Wu, A. (2019). Applications of Iron Oxide in Bacterial Infection and Co2+/N-(aminobut3r1)-N-(ethylisolumino1) functional flowerlike gold nanoparticles for Salmonella typhimurium detection. Talanta, 164, 275–282. https://doi.org/10.1016/j.talanta.2016.11.053

Xu, S., Ouyang, W., Xie, P., Lin, Y., Qiu, B., Lin, Z., Chen, G., & Guo, L. (2017). Highly uniform gold nanobipyramids for ultrasensitive colorimetric detection of influenza virus. Analytical Chemistry, 89(3), 1617–1623. https://doi.org/10.1021/acs.analchem.6b03711

Xu, C., Akakuru, O.U., Zheng, J., Wu, A. (2019). Applications of Iron Oxide-Based Magnetic Nanoparticles in the Diagnosis and Treatment of Bacterial Infections. Frontiers in Bioengineering and Biotechnology, 7:141. https://doi.org/10.3389/fbioe.2019.00141

Zeng, J., Zhang, Y., Zeng, T., Aleisa, R., Qiu, Z., Chen, Y., Huang, J., Wang, D., Yan, Z., Yin, Y. (2020). Anisotropic Plasmonic Nanostructures for Colorimetric Sensing. Nano Today, 32: 100855. https://doi.org/10.1016/j.nantod.2020.100855

Zhang, H., Zhao, Q., Li, X.F. and Le, X.C. (2007). Ultrasensitive assays for proteins. Analyst, 132(8): 724-737. https://doi.org/10.1039/B704256

Zhang, D. Carr, D.J., Alocilja, E.C., (2009). Fluorescent bio-barcode DNA assay for the detection of *Salmonella enterica* serovar Enteritidis. B*iosensors and Bioelectronics*, 24: 1377-1381. https://doi.org/10.1016/j.bios.2008.07.081

Zhang, X., Qi, B., Li Y., Zhang, S. (2009). Amplified electrochemical aptasensor for thrombin based on bio-barcode method. B*iosensors and Bioelectronics*, **25(1):** 259-262. https://doi.org/10.1016/j.bios.2009.06.026

Zheng, K., Setyawati, M.I., Leong, D.T., Xie, J. (2017). Antimicrobial Gold Nanoclusters. ACS Nano, 11, 6904-6910. https://doi.org/10.1021/acsnano.7b02035

Zheng, J., Ji, X., Du, M., Tian, S., & He, Z. (2018). Rational construction of a DNA nanomachine for HIV nucleic acid ultrasensitive sensing. Nanoscale, 10(36), 17206–17211. https://doi.org/10.1039/c8nr05206

Zou, L., & Ling, L. (2018). Ultrasensitive detection of HIV DNA with polymerase chain reaction-dynamic light scattering. Analytical Chemistry, 90(22), 13373–13377. https://doi.org/10.1021/acs.analchem.8b03052

BÖLÜM 8

Yüzey Zenginleştirilmiş Raman Spektroskopisi Uygulamalarında Metal Nano Parçacıkların Rolü

Muhammed Emre AYHAN[1]

GİRİŞ

Mühendislikte nano parçacıkların kullanımı, bir dizi uygulama alanında çeşitli avantajlar sunar. Nano parçacıkların benzersiz özellikleri sebebiyle malzemelerin, cihazların ve sistemlerin geliştirilmesi ve iyileştirilmesi için geniş bir yelpazede kullanım alanı söz konusudur. Malzemeler makro ve mikro boyutlarda sınırlı özelliklere sahipken nano boyutlara indikçe büyüklük, şekil, yüzey özellikleri ve kimyasal reaktivite gibi faktörlerin modifikasyonu ile mühendislik anlamında olağanüstü özellik ve performansların elde edilmesi mümkündür. Nano ölçekteki malzemelerin mekanik özellikleri, makro ölçektekilere göre farklılık gösterebilir. Nano parçacıklar, malzemelerin mukavemetini ve dayanıklılığını artırabilir. Nano malzemelerin düşük yoğunluğu, hafif ve dayanıklı malzemelerin tasarlanmasına imkân tanır. Nano parçacıklar, kataliz süreçlerinde yüksek aktivite ve seçicilik sağlar. Katalitik reaksiyonları hızlandırmak ve verimliliği artırmak için kullanılırlar. Küçük boyutları ve büyük yüzey alanları, yüksek katalitik aktivite sağlar. Bu özellikleri, kimyasal reaksiyon hızlarını artırarak ve seçiciliği iyileştirerek endüstriyel süreçlerde ve enerji dönüşümünde kullanılmalarını sağlar. Elektronik cihazlarda kullanılan metal nano parçacıklar, transistörlerden sensörlere kadar bir dizi uygulamada rol oynar. Özellikle altın ve gümüş nano parçacıklar,

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Fosmet, permetrin, karbaril ve sipermetrin, meyve ve sebze yetiştiriciliğinde ve hasat sonrası uygulamalarda kullanılan tipik pestisitlerdir. Toprakta, çevrede ve gıdalardaki pestisit kalıntıları, yüksek derecede toksik doğası nedeniyle insanlar için ciddi sağlık tehlikelerine neden olmaktadır. Gıdalardaki pestisit izlerinin tespitine yönelik mevcut yaklaşımlar etkisiz, güvenilirliği zayıf ve zaman alıcıdır. Eser miktarda pestisit tespitine yönelik basit, hızlı ve etkili bir yöntem geliştirmek için birçok çalışma yürütülmektedir. Bu bağlamda, Sivashanmugan ve ark., çeşitli pestisit kalıntılarını tespit etmek için Au@Ag@Au nano çubuklar ve altın nano-boşluk dizisi üretmek için nano-indentasyon ve odaklanmış iyon ışını yöntemini kullandı. Ayrıca Au@Ag@Au-NRs YZRS aktif alt taşları, düşük konsantrasyonlarda bile birçok pestisit kalıntısını verimli bir şekilde tespit etti (Sivashanmugan ve diğerleri, 2017).

Sonuç

Değişen ve gelişen hayat şartlarına karşı bilim ve teknolojiden beklenenlerin bugün her zamankinden daha fazla olduğu inkâr edilemez. Özellikle insan, hayvan, gıda ve çevre sağlığı konularında, erken teşhiste ve eser miktardaki spesifik moleküllerin tespitinde; güvenilir, hızlı, hassas, ucuz ve taşınabilir-giyilebilir test materyallerinin tasarımı ve üretimi çok kritik bir öneme sahiptir. Bu noktada üstün özelliklere sahip MNP'lerin ve diğer nano malzemelerin mükemmel uyumu kullanılarak geliştirilen YZRS aktif alt taşları ve YZRS tekniği umut verici bir yaklaşımdır. Yapılacak yeni çalışmalarda soy metaller başta olmak üzere bütün MNP'lerin şekil, boyut ve dağılımları gibi parametreler değiştirilerek ve hibrit yapıların modifikasyonu sağlanarak yüksek ZF değerlerine ve hassasiyete sahip YZRS aktif alt taşları üretilebilir ve saniyeler içerisinde çok düşük konsantrasyonlardaki spesifik moleküller mobil Raman cihazlarıyla güvenilir bir şekilde tespit edilebilir.

Kaynaklar

Abid, S. A., Muneer, A. A., Al-Kadmy, I. M., Sattar, A. A., Beshbishy, A. M., Batiha, G. E. S., & Hetta, H. F. (2021). Biosensors as a future diagnostic approach for COVID-19. Life sciences, 273, 119117.

Aldewachi, H., Chalati, T., Woodroofe, M. N., Bricklebank, N., Sharrack, B., & Gardiner, P. (2018). Gold nanoparticle-based colorimetric biosensors. Nanoscale, 10(1), 18-33.

Amendola, V., Scaramuzza, S., Agnoli, S., Polizzi, S., & Meneghetti, M. (2014). Strong dependence of surface plasmon resonance and surface enhanced Raman scattering on the composition of Au–Fe nanoalloys. Nanoscale, 6(3), 1423-1433.

Amendola, V., Scaramuzza, S., Litti, L., Meneghetti, M., Zuccolotto, G., Rosato, A., ... & Colombatti, M. (2014). Magneto-plasmonic Au-Fe alloy nanoparticles designed for multimodal SERS-MRI-CT imaging. Small, 10(12), 2476-2486.

Ando, J., Fujita, K., Smith, N. I., & Kawata, S. (2011). Dynamic SERS imaging of cellular transport pathways with endocytosed gold nanoparticles. Nano letters, 11(12), 5344-5348.

Asif, M., Ajmal, M., Ashraf, G., Muhammad, N., Aziz, A., Iftikhar, T., ... & Liu, H. (2020). The role of biosensors in coronavirus disease-2019 outbreak. Current Opinion in Electrochemistry, 23, 174-184.

Atkins, P., De Paula, J., & Friedman, R. (2014). Physical chemistry: quanta, matter, and change. Oxford University Press, USA.

Awada, C., Abdullah, M. M. B., Traboulsi, H., Dab, C., & Alshoaibi, A. (2021). SARS-CoV-2 receptor binding domain as a stable-potential target for SARS-CoV-2 detection by surface—Enhanced Raman spectroscopy. Sensors, 21(13), 4617.

Awiaz, G., Lin, J., & Wu, A. (2023, February). Recent advances of Au@ Ag core–shell SERS-based biosensors. In Exploration (Vol. 3, No. 1, p. 20220072).

Ayhan, M. E. (2020). A single-step fabrication of Ag nanoparticles and CVD graphene hybrid nanostructure as SERS substrate. Microelectronic Engineering, 233, 111421.

Ayhan, M. E. (2021). CVD graphene-based flexible and transparent SERS substrate towards L-tyrosine detection. Microelectronic Engineering, 241, 111546.

Ayhan, M. E., Kalita, G., Sharma, S., & Tanemura, M. (2013). Chemical vapor deposition of graphene on silver foil as a tarnish-resistant coating. physica status solidi (RRL)–Rapid Research Letters, 7(12), 1076-1079.

Bhattacharjee, G., Bhattacharya, M., Roy, A., Senapati, D., & Satpati, B. (2018). Core–shell gold@ silver nanorods of varying length for high surface-enhanced Raman scattering enhancement. ACS Applied Nano Materials, 1(10), 5589-5600.

Campion, A., & Kambhampati, P. (1998). Surface-enhanced Raman scattering. Chemical society reviews, 27(4), 241-250.

Campion, A., Ivanecky III, J. E., Child, C. M., & Foster, M. (1995). On the mechanism of chemical enhancement in surface-enhanced Raman scattering. Journal of the American Chemical Society, 117(47), 11807-11808.

Chatterjee, S., Ringane, A. B., Arya, A., Das, G. M., Dantham, V. R., Laha, R., & Hussian, S. (2016). A high-yield, one-step synthesis of surfactant-free gold nanostars and numerical study for single-molecule SERS application. Journal of Nanoparticle Research, 18, 1-9.

Choi, N., Dang, H., Das, A., Sim, M. S., Chung, I. Y., & Choo, J. (2020). SERS biosensors for ultrasensitive detection of multiple biomarkers expressed in cancer cells. Biosensors and Bioelectronics, 164, 112326.

Dong, J., Zhao, X., Gao, W., Han, Q., Qi, J., Wang, Y., ... & Sun, M. (2019). Nanoscale vertical arrays of gold nanorods by self-assembly: physical mechanism and application. Nanoscale research letters, 14, 1-9.

Ferraro, J. R. (2003). Introductory raman spectroscopy. Elsevier.

Fleischmann, M., Hendra, P. J., & McQuillan, A. J. (1974). Raman spectra of pyridine adsorbed at a silver electrode. Chemical physics letters, 26(2), 163-166.

Fu, J., Lai, H., Zhang, Z., & Li, G. (2021). UiO-66 metal-organic frameworks/gold nanoparticles based substrates for SERS analysis of food samples. Analytica Chimica Acta, 1161, 338464.

Gong, Z., Du, H., Cheng, F., Wang, C., Wang, C., & Fan, M. (2014). Fabrication of SERS swab for direct detection of trace explosives in fingerprints. ACS applied materials & interfaces, 6(24), 21931-21937.

Guan, W. J., Ni, Z. Y., Hu, Y., Liang, W. H., Ou, C. Q., He, J. X., ... & Zhong, N. S. (2020). Clinical characteristics of coronavirus disease 2019 in China. New England journal of medicine, 382(18), 1708-1720.

Han, X. X., Zhao, B., & Ozaki, Y. (2009). Surface-enhanced Raman scattering for protein detection. Analytical and bioanalytical chemistry, 394, 1719-1727.

Hasan, M. T., Gonzalez, R., Chipara, M., Materon, L., Parsons, J., & Alcoutlabi, M. (2021). Antibacterial activities of centrifugally spun polyethylene oxide/silver composite nanofibers. Polymers for Advanced Technologies, 32(6), 2327-2338.

Haynes, C. L., McFarland, A. D., & Van Duyne, R. P. (2005). Surface-enhanced Raman spectroscopy.

Huang, C., Wang, Y., Li, X., Ren, L., Zhao, J., Hu, Y., ... & Cao, B. (2020). Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. The lancet, 395(10223), 497-506.

Jiang, Y. X., Li, J. F., Wu, D. Y., Yang, Z. L., Ren, B., Hu, J. W., ... & Tian, Z. Q. (2007). Characterization of surface water on Au core Pt-group metal shell nanoparticles coated electrodes by surface-enhanced Raman spectroscopy. Chemical communications, (44), 4608-4610.

Jiang, Z., Zhang, Q., Zong, C., Liu, B. J., Ren, B., Xie, Z., & Zheng, L. (2012). Cu–Au alloy nanotubes with five-fold twinned structure and their application in surface-enhanced Raman scattering. Journal of Materials Chemistry, 22(35), 18192-18197.

Jindal, M., Nagpal, M., Singh, M., Aggarwal, G., & Dhingra, G. A. (2020). Gold nanoparticles-boon in cancer theranostics. Current Pharmaceutical Design, 26(40), 5134-5151.

Kahraman, M., Daggumati, P., Kurtulus, O., Seker, E., & Wachsmann-Hogiu, S. (2013). Fabrication and characterization of flexible and tunable plasmonic nanostructures. Scientific reports, 3(1), 3396.

Kamińska, A., Witkowska, E., Winkler, K., Dzięcielewski, I., Weyher, J. L., & Waluk, J. (2015). Detection of Hepatitis B virus antigen from human blood: SERS immunoassay in a microfluidic system. Biosensors and bioelectronics, 66, 461-467.

Karthika, A., Rosaline, D. R., Inbanathan, S. S. R., Suganthi, A., & Rajarajan, M. (2020). Fabrication of Cupric oxide decorated β-cyclodextrin nanocomposite solubilized Nafion as a high performance electrochemical sensor for l-tyrosine detection. Journal of Physics and Chemistry of Solids, 136, 109145.

Kavitha, C., Bramhaiah, K., & John, N. S. (2020). Low-cost electrochemical detection of L-tyrosine using an rGO–Cu modified pencil graphite electrode and its surface orientation on a Ag electrode using an ex situ spectroelectrochemical method. RSC advances, 10(39), 22871-22880.

Kedia, A., & Kumar, P. S. (2014). Halide ion induced tuning and self-organization of gold nanostars. Rsc Advances, 4(9), 4782-4790.

Kiefer, W. (2011). Surface enhanced Raman spectroscopy: analytical, biophysical and life science applications. John Wiley & Sons.

Kim, K., Kim, K. L., Choi, J. Y., Lee, H. B., & Shin, K. S. (2010). Surface enrichment of Ag atoms in Au/Ag alloy nanoparticles revealed by surface-enhanced Raman scattering of 2, 6-dimethylphenyl isocyanide. The Journal of Physical Chemistry C, 114(8), 3448-3453.

Kosović, M., Balarin, M., Ivanda, M., Đerek, V., Marciuš, M., Ristić, M., & Gamulin, O. (2015). Porous silicon covered with silver nanoparticles as surface-enhanced Raman scattering (SERS) substrate for ultra-low concentration detection. Applied spectroscopy, 69(12), 1417-1424.

Kumar, A., Roberts, D., Wood, K. E., Light, B., Parrillo, J. E., Sharma, S., ... & Cheang, M. (2006). Duration of hypotension before initiation of effective antimicrobial therapy is the critical determinant of survival in human septic shock. Critical care medicine, 34(6), 1589-1596.

Kundu, A., Rani, R., Ahmad, A., Kumar, A., Raturi, M., Gupta, T., ... & Hazra, K. S. (2022). Ultrasensitive and label-free detection of prognostic and diagnostic biomarkers of sepsis on a AgNP-laden black phosphorous-based SERS platform. Sensors & Diagnostics, 1(3), 449-459.

Kurdekar, A., Chunduri, L. A. A., Bulagonda, E. P., Haleyurgirisetty, M. K., Kamisetti, V., & Hewlett, I. K. (2016). Comparative performance evaluation of carbon dot-based paper immunoassay on Whatman filter paper and nitrocellulose paper in the detection of HIV infection. Microfluidics and Nanofluidics, 20, 1-13.

Langer, J., Jimenez de Aberasturi, D., Aizpurua, J., Alvarez-Puebla, R. A., Auguié, B., Baumberg, J. J., ... & Liz-Marzán, L. M. (2019). Present and future of surface-enhanced Raman scattering. ACS nano, 14(1), 28-117.

Lee, Y. W., Kim, M., Kang, S. W., & Han, S. W. (2011). Polyhedral bimetallic alloy nanocrystals exclusively bound by {110} facets: Au–Pd rhombic dodecahedra. Angewandte Chemie, 123(15), 3528-3532.

Leong, S. X., Leong, Y. X., Tan, E. X., Sim, H. Y. F., Koh, C. S. L., Lee, Y. H., ... & Ling, X. Y. (2022). Noninvasive and point-of-care surface-enhanced Raman scattering (SERS)-based breathalyzer for mass screening of coronavirus disease 2019 (COVID-19) under 5 min. ACS nano, 16(2), 2629-2639.

Li, D., Qu, L., Zhai, W., Xue, J., Fossey, J. S., & Long, Y. (2011). Facile on-site detection of substituted aromatic pollutants in water using thin layer chromatography combined with surface-enhanced Raman spectroscopy. Environmental science & technology, 45(9), 4046-4052.

Li, H., Huang, X., Hassan, M. M., Zuo, M., Wu, X., Chen, Y., & Chen, Q. (2020). Dual-channel biosensor for Hg2+ sensing in food using Au@ Ag/graphene-upconversion nanohybrids as metal-enhanced fluorescence and SERS indicators. Microchemical Journal, 154, 104563.

Li, J. F., Huang, Y. F., Ding, Y., Yang, Z. L., Li, S. B., Zhou, X. S., ... & Tian, Z. Q. (2010). Shell-isolated nanoparticle-enhanced Raman spectroscopy. nature, 464(7287), 392-395.

Li, J. M., Yang, Y., & Qin, D. (2014). Hollow nanocubes made of Ag–Au alloys for SERS detection with sensitivity of 10– 8 M for melamine. Journal of Materials Chemistry C, 2(46), 9934-9940.

Li, Y., Yuan, M., Khan, A. J., Wang, L., & Zhang, F. (2019). Peptide-gold nanocluster synthesis and intracellular Hg2+ sensing. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 579, 123666.

Lien, C. W., Tseng, Y. T., Huang, C. C., & Chang, H. T. (2014). Logic control of enzyme-like gold nanoparticles for selective detection of lead and mercury ions. Analytical chemistry, 86(4), 2065-2072.

Lippi, G., & Plebani, M. (2020). Procalcitonin in patients with severe coronavirus disease 2019 (COVID-19): a meta-analysis. Clinica chimica acta; international journal of clinical chemistry, 505, 190.

Liu, H., & Yang, Q. (2011). Facile fabrication of nanoporous Au–Pd bimetallic foams with high catalytic activity for 2-nitrophenol reduction and SERS property. Journal of Materials Chemistry, 21(32), 11961-11967.

Liu, J., Cui, H., Yan, S., Jing, X., Wang, D., & Meng, L. (2018). Gold nanostars decorated MnO2 nanosheets for magnetic resonance imaging and photothermal erasion of lung cancer cell. Materials Today Communications, 16, 97-104.

Liu, K., Bai, Y., Zhang, L., Yang, Z., Fan, Q., Zheng, H., ... & Gao, C. (2016). Porous Au–Ag nanospheres with high-density and highly accessible hotspots for SERS analysis. Nano letters, 16(6), 3675-3681.

Liu, X., Osada, M., Kitamura, K., Nagata, T., & Si, D. (2017). Ferroelectric-assisted gold nanoparticles array for centimeter-scale highly reproducible SERS substrates. Scientific Reports, 7(1), 3630.

Liu, Y., Ouyang, Q., Li, H., Chen, M., Zhang, Z., & Chen, Q. (2018). Turn-on fluoresence sensor for Hg2+ in food based on FRET between aptamers-functionalized upconversion nanoparticles and gold nanoparticles. Journal of agricultural and food Chemistry, 66(24), 6188-6195.

Lu, R., Zhao, X., Li, J., Niu, P., Yang, B., Wu, H., ... & Tan, W. (2020). Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. The lancet, 395(10224), 565-574.

Lu, Y., Lin, Y., Zheng, Z., Tang, X., Lin, J., Liu, X., ... & Feng, S. (2018). Label free hepatitis B detection based on serum derivative surface enhanced Raman spectroscopy combined with multivariate analysis. Biomedical optics express, 9(10), 4755-4766.

Mayr, F. B., Yende, S., & Angus, D. C. (2014). Epidemiology of severe sepsis. Virulence, 5(1), 4-11.

Miao, P., & Tang, Y. (2019). Gold nanoparticles-based multipedal DNA walker for ratiometric detection of circulating tumor cell. Analytical chemistry, 91(23), 15187-15192.

Mitra, S., Chakraborty, A. J., Tareq, A. M., Emran, T. B., Nainu, F., Khusro, A., ... & Simal-Gandara, J. (2022). Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. Journal of King Saud University-Science, 34(3), 101865.

Mocan, L., Matea, C., Tabaran, F. A., Mosteanu, O., Pop, T., Puia, C., ... & Mocan, T. (2016). Selective in vitro photothermal nano-therapy of MRSA infections mediated by IgG conjugated gold nanoparticles. Scientific Reports, 6(1), 39466.

Moskovits, M. (1982). Surface selection rules. The Journal of Chemical Physics, 77(9), 4408-4416.

Niu, W., Chua, Y. A. A., Zhang, W., Huang, H., & Lu, X. (2015). Highly symmetric gold nanostars: crystallographic control and surface-enhanced Raman scattering property. Journal of the American Chemical Society, 137(33), 10460-10463.

Obeng-Gyasi, E. (2019). Sources of lead exposure in various countries. Reviews on environmental health, 34(1), 25-34.

Ortiz-Castillo, J. E., Gallo-Villanueva, R. C., Madou, M. J., & Perez-Gonzalez, V. H. (2020). Anisotropic gold nanoparticles: A survey of recent synthetic methodologies. Coordination Chemistry Reviews, 425, 213489.

Paccotti, N., Chiadò, A., Novara, C., Rivolo, P., Montesi, D., Geobaldo, F., & Giorgis, F. (2021). Real-Time Monitoring of the In Situ Microfluidic Synthesis of Ag Nanoparticles on Solid Substrate for Reliable SERS Detection. Biosensors, 11(12), 520.

Paoli, C. J., Reynolds, M. A., Sinha, M., Gitlin, M., & Crouser, E. (2018). Epidemiology and costs of sepsis in the United States—an analysis based on timing of diagnosis and severity level. Critical care medicine, 46(12), 1889.

Pathak, N. K., Ji, A., & Sharma, R. P. (2014). Tunable properties of surface plasmon resonances: the influence of core–shell thickness and dielectric environment. Plasmonics, 9, 651-657.

Peng, L., Liu, J., Xu, W., Luo, Q., Chen, D., Lei, Z., ... & Gao, Z. (2020). SARS-CoV-2 can be detected in urine, blood, anal swabs, and oropharyngeal swabs specimens. Journal of medical virology, 92(9), 1676-1680.

Prucha, M., Bellingan, G., & Zazula, R. (2015). Sepsis biomarkers. Clinica chimica acta, 440, 97-103.

Qian, X. M., & Nie, S. M. (2008). Single-molecule and single-nanoparticle SERS: from fundamental mechanisms to biomedical applications. Chemical Society Reviews, 37(5), 912-920.

Raman, C. V., & Krishnan, K. S. (1928). A new class of spectra due to secondary radiation. Part I.

Sanchez, J. E., Jaramillo, S. A., Settles, E., Velazquez Salazar, J. J., Lehr, A., Gonzalez, J., ... & Keim, P. (2021). Jose Yacaman M. Detection of SARS-CoV-2 and its S and N proteins using surface enhanced Raman spectroscopy. RSC Adv, 11, 25788-25794.

Sardar, M., Perwez, M., Ahmad, R., Mukherjee, J., & Gupta, M. N. (2018). Immobilization of enzymes on magnetic nanoparticles. Encyclopedia of Nanoscience and Nanotechnology, ed. HS Nalwa (Los Angeles, CA: American Scientific Publishers).

Selimoğlu, F., & Ayhan, M. E. (2023). Silver nanoparticle decorated graphene-based SERS electrode towards procalcitonin detection. Vibrational Spectroscopy, 126, 103539.

Shiohara, A., Langer, J., Polavarapu, L., & Liz-Marzán, L. M. (2014). Solution processed polydimethylsiloxane/gold nanostar flexible substrates for plasmonic sensing. Nanoscale, 6(16), 9817-9823.

Singer, M., Deutschman, C. S., Seymour, C. W., Shankar-Hari, M., Annane, D., Bauer, M., ... & Angus, D. C. (2016). The third international consensus definitions for sepsis and septic shock (Sepsis-3). Jama, 315(8), 801-810.

Sivashanmugan, K., Huang, W. L., Lin, C. H., Liao, J. D., Lin, C. C., Su, W. C., & Wen, T. C. (2017). Bimetallic nanoplasmonic gap-mode SERS substrate for lung normal and cancer-derived exosomes detection. Journal of the Taiwan Institute of Chemical Engineers, 80, 149-155.

Song, C., Li, J., Sun, Y., Jiang, X., Zhang, J., Dong, C., & Wang, L. (2020). Colorimetric/SERS dual-mode detection of mercury ion via SERS-Active peroxidase-like Au@ AgPt NPs. Sensors and Actuators B: Chemical, 310, 127849.

Song, C., Wang, Z., Zhang, R., Yang, J., Tan, X., & Cui, Y. (2009). Highly sensitive immunoassay based on Raman reporter-labeled immuno-Au aggregates and SERS-active immune substrate. Biosensors and Bioelectronics, 25(4), 826-831.

Sun, D., Zhang, G., Jiang, X., Huang, J., Jing, X., Zheng, Y., ... & Li, Q. (2014). Biogenic flower-shaped Au–Pd nanoparticles: synthesis, SERS detection and catalysis towards benzyl alcohol oxidation. Journal of Materials Chemistry A, 2(6), 1767-1773.

Tai, C. Y., Wang, Y. H., & Liu, H. S. (2008). A green process for preparing silver nanoparticles using spinning disk reactor. AIChE Journal, 54(2), 445-452.

Tzeng, Y., & Lin, B. Y. (2020). Silver SERS adenine sensors with a very low detection limit. Biosensors, 10(5), 53.

Tzeng, Y., & Lin, B. Y. (2020). Silver-based SERS pico-molar adenine sensor. Biosensors, 10(9), 122.

Wang, Y., Jin, Y., Xiao, X., Zhang, T., Yang, H., Zhao, Y., ... & Li, Q. (2018). Flexible, transparent and highly sensitive SERS substrates with cross-nanoporous structures for fast on-site detection. Nanoscale, 10(32), 15195-15204.

Wei, J., Qiu, J., Li, L., Ren, L., Zhang, X., Chaudhuri, J., & Wang, S. (2012). A reduced graphene oxide based electrochemical biosensor for tyrosine detection. Nanotechnology, 23(33), 335707.

Wu, L. A., Li, W. E., Lin, D. Z., & Chen, Y. F. (2017). Three-dimensional SERS substrates formed with plasmonic core-satellite nanostructures. Scientific reports, 7(1), 13066.

Xu, W., Ling, X., Xiao, J., Dresselhaus, M. S., Kong, J., Xu, H., ... & Zhang, J. (2012). Surface enhanced Raman spectroscopy on a flat graphene surface. Proceedings of the National Academy of Sciences, 109(24), 9281-9286.

Xu, W., Zhao, A., Zuo, F., Khan, R., Hussain, H. M. J., & Li, J. (2020). A highly sensitive DNAzyme-based SERS biosensor for quantitative detection of lead ions in human serum. Analytical and Bioanalytical Chemistry, 412, 4565-4574.

Yang, X., Li, J., Zhao, Y., Yang, J., Zhou, L., Dai, Z., ... & Liang, W. (2018). Self-assembly of Au@ Ag core–shell nanocuboids into staircase superstructures by droplet evaporation. Nanoscale, 10(1), 142-149.

Yazgan, N. N., Boyacı, İ. H., Temur, E., Tamer, U., & Topcu, A. (2010). A high sensitive assay platform based on surface-enhanced Raman scattering for quantification of protease activity. Talanta, 82(2), 631-639.

Ye, X., Qian, H., Xu, P., Zhu, L., Longnecker, M. P., & Fu, H. (2009). Nephrotoxicity, neurotoxicity, and mercury exposure among children with and without dental amalgam fillings. International journal of hygiene and environmental health, 212(4), 378-386.

Yuan, A., Wu, X., Li, X., Hao, C., Xu, C., & Kuang, H. (2019). Au@ gap@ AuAg nanorod side-by-side assemblies for ultrasensitive SERS detection of mercury and its transformation. Small, 15(27), 1901958.

Zengin, A., Tamer, U., & Caykara, T. (2017). SERS detection of hepatitis B virus DNA in a temperature-responsive sandwich-hybridization assay. Journal of Raman Spectroscopy, 48(5), 668-672.

Zhang, B., Pinsky, B. A., Ananta, J. S., Zhao, S., Arulkumar, S., Wan, H., ... & Dai, H. (2017). Diagnosis of Zika virus infection on a nanotechnology platform. Nature medicine, 23(5), 548-550.

Zhang, D., Zhang, X., Ma, R., Deng, S., Wang, X., Wang, X., ... & Li, J. (2021). Ultra-fast and onsite interrogation of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) in waters via surface enhanced Raman scattering (SERS). Water research, 200, 117243.

Zhang, J. J., Dong, X., Cao, Y. Y., Yuan, Y. D., Yang, Y. B., Yan, Y. Q., ... & Gao, Y. D. (2020). Clinical characteristics of 140 patients infected with SARS-CoV-2 in Wuhan, China. Allergy, 75(7), 1730-1741.

Zhang, M., Li, X., Pan, J., Zhang, Y., Zhang, L., Wang, C., ... & Lu, G. (2021). Ultrasensitive detection of SARS-CoV-2 spike protein in untreated saliva using SERS-based biosensor. Biosensors and Bioelectronics, 190, 113421.

Zhang, X., Zhang, X., Luo, C., Liu, Z., Chen, Y., Dong, S., ... & Xiao, X. (2019). Volume-enhanced raman scattering detection of viruses. Small, 15(11), 1805516.

Zheng, J., Li, X., Gu, R., & Lu, T. (2002). Comparison of the surface properties of the assembled silver nanoparticle electrode and roughened silver electrode. The Journal of Physical Chemistry B, 106(5), 1019-1023.

Zhong, L. B., Yin, J., Zheng, Y. M., Liu, Q., Cheng, X. X., & Luo, F. H. (2014). Self-assembly of Au nanoparticles on PMMA template as flexible, transparent, and highly active SERS substrates. Analytical chemistry, 86(13), 6262-6267.

Zhou, X., Li, P., Wu, X., Lin, X., Zhao, L., Huang, H., ... & Sun, P. (2022). Multifunctional biosensor constructed by Ag-coating magnetic-assisted unique urchin core porous shell structure for dual SERS enhancement, enrichment, and quantitative detection of multi-components inflammatory markers. Biosensors and Bioelectronics, 210, 114257.

Zhou, X., Li, P., Wu, X., Lin, X., Zhao, L., Huang, H., ... & Sun, P. (2022). Multifunctional biosensor constructed by Ag-coating magnetic-assisted unique urchin core porous shell structure for dual SERS enhancement, enrichment, and quantitative detection of multi-components inflammatory markers. Biosensors and Bioelectronics, 210, 114257.

Zhu, X., Radovic-Moreno, A. F., Wu, J., Langer, R., & Shi, J. (2014). Nanomedicine in the management of microbial infection–overview and perspectives. Nano today, 9(4), 478-498.

Zou, X., & Dong, S. (2006). Surface-enhanced Raman scattering studies on aggregated silver nanoplates in aqueous solution. The Journal of Physical Chemistry B, 110(43), 21545-21550.