



REVIEW ARTICLE

Carbon nanotubes in electrochemical sensors for pharmaceutical analysis

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Abstract

For nature of medication control the ion-selective electrodes (ISEs) had shown large applications. Lately, carbon nanotubes (CNTs) have been use up. CNTs have amazingly captivating physicochemical characters, as masterminded development with high point extent, high mechanical strength, high electrical conductivity, in height heat conductivity, great surface area and metallic or semi-metallic direct. For making bio and electrochemical sensors the electron office moves amid the electro-dynamic kinds and the offers of electrodes unprecedented assurance. The blend of these characterization formulates CNTs uncommon substances through the possible for grouped applications. In this research, shows to the various type of carbon nanotubes with ion selective electrodes for medication analysis.

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1. Introduction

Carbon Nanotubes (CNTs) are enormous particles of unadulterated carbon that are long, slim and tube formed, around 1-3 nm (1nm = 1billionth of a meter) in width, and countless nanometer of nanometer long. As specific particles, nanotubes are multiple times more grounded than steel and one-6th of its weight. Some CNTs can be incredibly proficient conveyor of power and warmth; contingent upon their setup, some are go about as semiconductor. There are two crystalline types of unadulterated carbon in nature, which are Diamond and Graphite. Diamond. is the hardest one due the sp^3 hybridization in which four bonds are coordinated towards the sides of an ordinary tetrahedron. Furthermore, in graphite, which appearances a hexagonal structure and faces the sp^2 hybridization in which carbon iota is associated equitably to three corners (1200) in xy plane. Round and hollow molded CNTs are one of the allotropes of carbon, moderate between fullerene enclosures and level graphene [1]. As well CNTs are

new and intriguing individuals from the carbon electrode family offering electronic characterizes and novel mechanical got together with substance steadiness [2-4]. Up until now, they have not been utilized broadly in electro scientific science yet this is probably going to change sooner rather than later. Carbon nanotubes are shaped to two designs: single-walled (SWNT), MWNTs and multi-walled(MWNT) are made out of shut graphene tubules and concentric, both with sheet of a rolled-up graphene. An extent of breadths be able to made as of a couple to around 30 nm. Most of the researches in this area over the years has used MWNTs in light of the trouble in creating stage unadulterated and situated SWNTs. A SWNT is prepared by a solitary graphite sheet rolled consistently with a measurement of 1-2 nm. SWNTs are typically planned in a standard illustration of gatherings that involve tens to numerous cylinders in contact with each other. Nanotubes can be filled in a "spaghetti mesh-like" game-plan or in an orchestrated show or organization [4]. As explores recorded nanotubes can be produced by discharge of curve, removal of

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laser, and method: deposition of chemical vapor [4]. The underlying two use a solid formal herald as the source of carbon and remember vanishing for temperatures in heights (degrees centigrade reach to thousands). These grounded methods produce magnificent the structures of nanotube, even with the incidental effects that are molded CVD uses source of gas (hydrocarbon) and a molecule of metal catalyst for a "seed" of nanotube improvement. Advancement by deposition of chemical vapor happens in lesser temperatures (500-1000 °C) than the round portion delivery or removal of laser strategies. The availability of the driving force is a fundamental development in the improvement of nanotube. Impulses have been orchestrated as layers of thin metal, salt layers as a slight metal, and dissipated nanoparticles [5]. Co, Fe, and their blends with Mo are utilized as per catalytic agent. Together MWNTs and SWNTs can be delivered by every one of the three strategies. Extraordinary advancement has been made as of late, especially using the CVD technique, delivering SWNTs with flawlessness and high crystallinity. Can be developed the carbon nanotubes on leading Si, , Pt, , Au and glass. Three initial substrates are helpful to construction nanotubes into electrodes of electrochemical. Three various states nanotubes have been designed as an electrode of electrochemical.

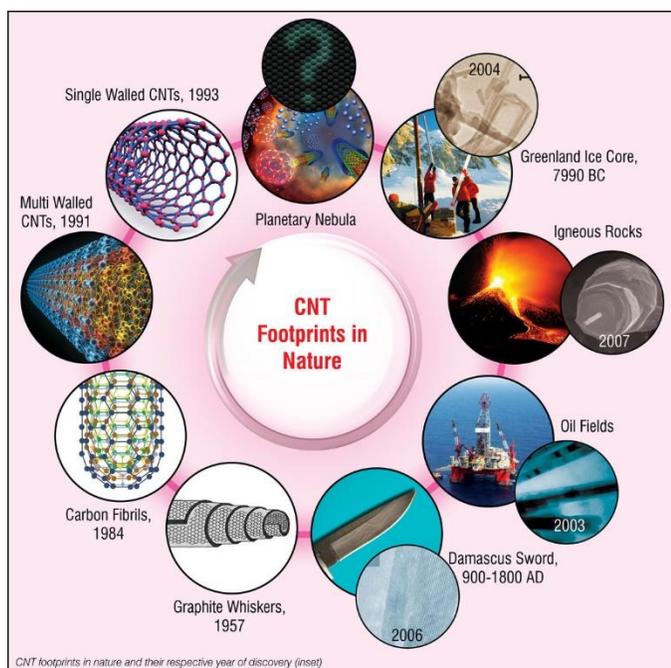


Figure 1: Types of CNTs in nature and their particular year of finding.

As initially , nanotubes have been arranged into what might measure up to an electrode of carbon paste by dispersing into a pit of Teflon. Researchers establish that a blend of 40% mineral oil and 60% nanotube conveyed an electrode with great characters of electrochemical .Additional, the "spaghetti mesh-like" strategy of nanotubes be able to actually joined to a surface of electrode. Other researcher cast an association of

SWNTs on an electrode of glassy carbon [6]. It was refined by scattering in N,N-dimethylformamide by weight 1 mg of nanotubes, the response of electrochemical for this electrode, regardless, comprises a responsibility equally the primary support electrode and the nanotubes. Also, an discrete nanotube or group can be made into a microelectrode. Crooks and collaborators reported the electrochemical direct of a single nanotube, associated with a main wire and secured with polyphenol [7]. The use of this carbon kind in electro insightful science is new so much that there isn't a bounty of composing until now open on procedures of pretreatment and their sufficiency. In Fig.1 shows the types of CNTs and the year of finding their.

2. Chemical Properties

The CNT surface ebb and flow, contrast with the graphene sheet, causes the blending of the σ and π orbital to drives the hybridization amid the orbitals and improves the chemical reactivity. Carbon nanotube reactivity is straightforwardly identified with the π -orbital befuddle brought about by an expanded shape as the level of hybridization increases as the measurement of a SWNT gets more modest Therefore, a differentiation should be made between the sidewall and the end covers of a nanotube. For a comparative clarification, a humbler nanotube distance across achieves extended reactivity. Covalent association of sub-nuclear species to totally sp^2 -sustained carbon atoms on the nanotube sidewalls winds up being problematic. Accordingly, nanotubes can be considered as normally chemically inert [1].

2.1 Sensors of Electrochemical

A substance sensor is a little tool that used to direct assessment of the analysis of sample, such a tool is good for replying continually with reversibly and doesn't trouble the sample. Through solidifying the test sample managing also assessment stages, sensors remove the necessity for test collection and readiness. Sensors substance include a transduction segment covered with layer of chemical recognition or a biological. This layer teams up with the real analysis, and the variations of chemical coming about due to this affiliation are interpreted by the part of transduction into electrical signs. Sensors of electrochemical indicate a significant subclass for sensors of chemical wherein transduction segment of electrode is used. Such tools keep firm on a primary footing mid sensors as of now accessible, have shown up at the stage of business, and have originate a colossal extent of critical applications in the clinical topics, environmental, mechanical and agrarian investigations. Various procedures for association for sensors of electrochemical. One of them relies upon yield signal from sensor of electrochemical. Thusly sensors of electrochemical grouped to two significant groups: voltammetry sensors also potentiometric.

Electrochemical sensors (ECS) have been demonstrated as a cheap and basic scientific strategy with striking detection

sensitivity, reproducibility, and simplicity of scaling down as opposed to another methods of instrumental analysis. Then CNTs have fascinating electrochemical characters, promoted via the development of edge-plane-like graphite objections at the CNT closes, it will in general be there used for improvement of electrochemical sensors (CNT-ECS). CNTECS show small limit of detection, in height sensitivity and speedy reply because of the sign improvement given by in height area of surface, small overvoltage, plus fast electrode energy. Due to of meaning of CNTs and electrochemical sensors as well as shows benefits and employments of CNTs in sensors of electrochemical [8].

2.2 Potentiometric sensors

Ion-selective electrodes (ISEs) as a potentiometric sensor have been the topic of consistent exploration endeavors. This gathering of substance sensors depicted as direct in arranging, strong in activity and modestly specific in scientific execution. A few types of ISEs enhance standard tools in laboratories of analytical [8]. Ideally, sensors of potentiometric recognize the molecule development in the test sample which makes it an astounding group of chemical sensors that might be very beneficial in speciation readings or bioavailability. Nernst Equation is consistently utilized to depict the preeminent response of for example a cell:

$$EMF = K + (RT/zF) \ln aI \quad (1)$$

EMF: is the power of electromotive, K is a reliable potential responsibility that regularly fuses the liquid crossing point potential at electrode as reference, aI: is the action of test for the molecule I with charge z, and R, T, and F are the consistent of gas, complete temperature, and steady of Faraday consistent, separately [9]. Note that the activity of particle effectually portrays the supposed free, or uncompleted, assembly of the analytic, which is routinely the relevant fundamental stimulus in biochemical or chemical responses. Ion Selective Electrode has been usually utilized in numerous kinds of research for significant long time. The membrane of sensor for ISE can maybe choose explicit particle also well-known as specific ion electrode. It demonstrates the activity of particle (ion) which dissolved in solution and translates it into an electrical potential. Four kinds of ISE: electrode of glass membrane, electrode of gas sensing, electrode of solid state, and electrode of liquid membrane. Liquid membrane electrode is planned utilizing ion selective membrane as a essential piece of the electrode. The benefits of utilizing liquid membrane are because of its in height selectivity, useful and practical. Additionally, molecular recognition as specific can be accomplished with the guide of appropriate particle transporters for the transference device [10].

2.3 Pharmaceutical analysis

Medication analysis should be accomplished during all method

for drug improvement (11-13), from the start period of mix, itemizing, security testing and quality control to toxicological and pharmacological assessments in creatures and individuals in measure progression including preclinical and clinical fundamentals (14,15). After association to patients, analytical assessments are major for bioavailability testing and moreover for surveying their reasonability and viability of the necessary estimations of the required measurements of medication form (16, 17).

Quantitative analysis of fixing content in drug definitions and besides after application in human normal fluids is unavoidable. While diverse scientific strategies have been delivered for this point, electrochemical methodology have been considered as delicate, basic working, capable and cost employable strategies which can be rapidly and accurately used for drug test (17). Appeared differently in relation to other scientific methods, electrochemical affirmation has shown to be exceptionally sensitive and reliable with less impedance from non-electro- active species for the confirmation of wide extent of medication subject matter experts (18, 19).

In the course of recent many years, electrochemical conduct of medications, for example, lamotrigine naltrexone, phenothiazine, paracetamol, theophylline, sumatriptan, ascorbic corrosive, mercaptopurine, sumatriptan gabapentin, benzodiazepines, tramadol and so on has been broadly explored and an incredible pattern in drug analysis can be seen for creating electrochemical sensors. Also, gifted medication conveyance systems or implantable sensors for the quick recognition of biomarker and the arrival of restorative specialists on request can be planned dependent on these sensors (20).

2.4 Carbon nanostructured based electrode modification

Electrochemical methods have been broadly utilized for both each quantitative and qualitative analysis of inorganic and organic composites. In electrochemistry, working electrode surface assumes a significant part as the sensitivity and selectivity of the estimations is profoundly relied upon its characterizes. [21-22]. Different techniques have been used for application electrode change via carbon nanostructures. By and large, adjustment of electrode incorporates surface alteration or bulk. In least complex strategy, suspension of different kinds of carbon nanostructures is ready in an appropriate inorganic or organic dissolvable like water, dimethyl structure amide (DMF), or combination of them (23, 24). Then, at that point, the improved ampleness of this suspension was drop projected on the electrode surface, on which a meager layer of modifier is framed get-togethers vaporization (23-25). Even however the activity of this technique is exceptionally simple, the scattering of certain materials irrelevant solvents is unimaginable. For instance, solid cooperation between multi walled carbon nanotubes (MWCNTs) upsets their scattering in any dissolvable. Outstandingly, even in the wake of applying long time and concentrated sonication for scattering them, the resulted

suspension isn't steady and MWCNTs promptly precipitate from the dissolvable. Different kinds of carbon based nanostructures were utilized in electrode adjustment like multi and single -walled carbon nanotubes (26-35), graphene oxide

and decreased graphene oxide (36-40), graphene (41-44), fullerenes (45), carbon nanoparticles (46-55), carbon black (56-58). There are different electrodes were equipped relied upon carbon nanotube for assessment drugs shown in Table 1.

Table1: Type of ion selective electrodes based on carbon nanotubes (CNTs)

S. No.	Name of Electrodes	Characterization of electrodes	Ref.
1	Multi-walled carbon nanotubes for evaluation of tetracycline	Linear concentrations = 2.0×10^{-5} to 3.1×10^{-4} mol. L ⁻¹ . Sensitivity = $1.2 \times 10^4 \mu\text{A L mol}^{-1}$. Detection limit = 3.6×10^{-7} mol. L ⁻¹ . %RSD = less than 6.0	59
2	Carbon Nanotube/Silicone Rubber for determination of Propranolol	Linear ranges = up to 7.0 m mol. L ⁻¹ square wave voltammetry = 5.4 m mol. L ⁻¹ LODs = 0.12 and 0.078 mmol.L ⁻¹	60
3	Carbon Nanotubes or Gold Nanoparticles	Limit of detection = $1.52 \pm 0.89 \mu\text{M}$ and $1.29 \pm 0.48 \mu\text{M}$ Sensitivity = $0.98 \pm 0.41 \mu\text{A } \mu\text{M}^{-1}$ cm ⁻² and $1.43 \pm 0.26 \mu\text{A } \mu\text{M}^{-1}$ cm ⁻²	61
4	Modified glassy carbon electrode of calcium with Multiwall carbon nanotube	Linear range = 0.01 to 0.3 $\mu\text{g /ml}$ and 0.025 to 0.3 $\mu\text{g/ml}$ LOD = 0.005 $\mu\text{g/ml}$ and 0.01 $\mu\text{g/ml}$.	62
5	Multi-Wall Carbon Nanotubes for determination of various drugs	Linear range = 1.0×10^{-5} - 5.0×10^{-4} , 5.0×10^{-7} - 2.0×10^{-5} , 2.0×10^{-6} - 1.0×10^{-5} and 2.0×10^{-7} - 6.0×10^{-5} mol. L ⁻¹ . Detection limit = 1.0×10^{-5} , 5.0×10^{-7} , 1.0×10^{-6} , and $2.0 \times 10^{-7} \mu\text{g.mL}^{-1}$. r value = 0.9997 , 0.9995, 0.9997 and 0.9990.	63
6	Multi-walled carbon nanotube with glassy carbon electrode of atenolol	Linear range = $3 \times 10^{-5} \mu\text{M}$ and $9 \times 10^{-2} \text{Mm}$. limit of detection = $7.67 \times 10^{-5} \text{mM}$ and $2.5 \times 10^{-4} \text{mM}$	64
7	Carbon nanotube for determination of tramadol	Linear range = 5- 25 M detection limit (LOD) = 0.776 μM . R ² =0.999	65
8	Multi-walled carbon nanotube paste electrode of pentoxifylline	Linear range = 3.0×10^{-5} to $2.0 \times 10^{-4} \text{M}$ Detection limit = $1.69 \times 10^{-7} \text{M}$	66
9	Nano sized material of cobalt ferrite (np-CoFe2O4)	Detection limit = 250 nM ,350 nM and 300 nM and 400 nM. Linear range = 3 μM to 200 μM & 3 μM –160 μM for paracetamol 3 μM –180 μM & 5 μM to 200 for dopamine	67
10	Multi walled carbon nanotube (MWCNT) to Determination of Amitriptyline Drug	Linear range = 0.5 to 20.0 M Detection limit(LOD) = 0.0845 M and LOQ of 0.282 M	68
11	Multi walled Carbon Nanotubes for determination of Antihyperlipidemic Simvastatin	Detection limit = $2.4 \times 10^{-7} \text{M}$ Limit of quantification = $8 \times 10^{-7} \text{M}$	69
12	Multi walled carbon nanotube electrode with an entrapped nimesulide	%Recovery = 98.4% Detection and quantification limits = 1.6 nM and 5.5 nM.	70
13	Multi walled carbon nanotubes of an antipyretic and analgesic drug paracetamol	Linearly range = 0.02 to 28 Mm Sensitivity = $1.133 \mu\text{A } \mu\text{M}^{-1}$. Detection limit = 0.0052 Mm	71
14	Carbon Nanotube for the Determination of Tramadol Hydrochloride	Linearly range = 1.0×10^{-7} – 1.0×10^{-2} , 1.0×10^{-6} – 1.0×10^{-1} and 1.0×10^{-8} – 1.0×10^{-2} mol. L ⁻¹ Slope = 56.36, 55.32, and 54.33 (mV/ decade)	72
15	Carbon Nanotubes Modified for determination Selegiline Hydrochloride	Linearly range = 1.0×10^{-5} to $1.0 \times 10^{-2} \text{M}$ %Mean recovery = 95.2 to 103.5% %RSD = 0.2–0.8%. Detection limit = 1.52 to 21.26 $\mu\text{g/L}$, limit of quantification = 1.52 to 20.36 $\mu\text{g/L}$	73
16	MWCNTs/Fe-Co doped TNTs nanocomposite of sulphiride	Nernstian slopes = 57.1 ± 0.4 , 56 ± 0.5 and $58.8 \pm 0.2 \text{mV decade}^{-1}$ Detection limits = 7.6×10^{-7} , 1.58×10^{-6} and $8.7 \times 10^{-8} \text{mol. L}^{-1}$ Quantification limits = 2.5×10^{-6} , 5.2×10^{-6} and $2.9 \times 10^{-7} \text{mol. L}^{-1}$ Lifetime = 20, 18, and 25 weeks for sensors	74
17	Fe ₂ O ₃ @MWCNTs for Ivabradine Drug Determination	Nernstian slope = of 56mV decade^{-1} within the IVR Linear range = 1.0×10^{-3} to $9.8 \times 10^{-8} \text{M}$ Detection limit = 630 to 98 nM	75

3. Conclusions

In the evolution of technology, the study field is increasing exceptionally, while the studied object is reducing day by day. Nanotechnology and nano science is next weapon which can bring the great revolution in the history of technology. Applications of CNTs are excellent if we avoid the toxic side. Improvements in the previous few years have delineated the possibly upsetting effect of nano materials, particularly in biomedical imaging, drug conveyance, bio-detecting, and the plan of practical nano composites, high surface of area to ratio of volume allows us to fabricate more affordable for many applications than other material.

References

- [1] Sumio I., Toshinari I., (1993). "Single-shell carbon nanotubes of 1-nm diameter".
- [2] S. Iijima, Nature 349, 315 (1982).
- [3] D. N. Futaba, K. Hata, T. Yamada, K. Mizuno, M. Yumura, S. Iijima, Phys. Rev. Lett. 95, 056104 (2005).
- [4] H. Dai, Acc. Chem. Res. 35, 1035 (2002).
- [5] K. Mizuno, K. Hata, T. Saito, S. Ohshima, M. Yumura, S. Iijima, J. Phys. Chem. B 109, 2632(2005).
- [6] F. Valentini, A. Amine, S. Orlanducci, M. L. Terranova, G. Palleschi, Anal. Chem. 75, 5413 (2003).
- [7] J. K. Campbell, L. Sun, R. M. Crooks, J. Am. Chem. Soc. 121, 3779 (1999).
- [8] Mazloum-Ardakani, M.; Jalayer, M.; Naeimi, H.; Heidarneshad, A. & Zare, H.R. (2006). Highly selective oxalate-membrane electrode based on 2,2-[1,4-butandiyl bis(nitrilo propylidene)]bis-1-naphtholato copper(II). Biosenso. Bioelectron., Vol.21, pp.1156–1162, ISSN 0956-5663.
- [9] Wang, J. (2006). Analytical Electrochemistry (Third Edition), ISBN-13 978-0-471-67879-3, John Wiley & Sons, Hoboken, New Jersey.
- [10] F. Faridbod, M.R. Ganjali, R. Dinarvand, P. Norouzi, The fabrication of potentiometric membrane sensors and their applications, Afr. J. Biotechnol., 25 (2007) 2960-2987.
- [11] Akay C, Tuncer D, Egim I, Sayal A, Aydin A, Özkan Y and Gül H. Rapid and simultaneous determination of acetylsalicylic acid, paracetamol, and their degradation and toxic impurity products by HPLC in pharmaceutical dosage forms. Turk. J. Med. Sci. (2008) 38: 167-73.
- [12] Badyal PN, Sharma C, Kaur N, Shankar R, Pandey A and Rawal RK. Analytical techniques in simultaneous estimation: An overview. Austin J. Anal. Pharm. Chem. (2015) 2: 1037-50.
- [13] Bunaciu AA, Aboul-Enein HY and Fleschin S. Application of fourier transform infrared spectrophotometry in pharmaceutical drugs analysis. Appl. Spectrosc. Rev. (2010) 45: 206-19.
- [14] Barile FA. Published the chapter: Clinical toxicology: Principles and Mechanisms. 1st ed. CRC Press, Washington D.C. (2003).
- [15] Adams IB and Martin BR. Cannabis: pharmacology and toxicology in animals and humans. Addiction (1996) 91: 1585-614.
- [16] Dustin C. An investigation into formulation and therapeutic effectiveness of nanoparticle drug delivery for select pharmaceutical agents. East Tennessee State University (2016) Paper 3024.
- [17] Siddiqui MR, AlOthman ZA and Rahman N. Analytical techniques in pharmaceutical analysis: A review. Arabian J. Chem. (2013) 10: S1409-S1421.
- [18] Abo El-Maali N. Voltammetric analysis of drugs. Bioelectrochem (2004) 64: 99-107.
- [19] Gupta VK, Jain R, Radhapyari K, Jadon N and Agarwal S. Voltammetric techniques for the assay of pharmaceuticals-A review. Anal. Biochem. (2011) 408: 179-96.
- [20] Ghorbani-Bidkorbeh F. electrochemical sensors and biosensors represent very promising tools in pharmaceutical sciences. Iran. J. Pharm. Res. (2015) 14: 663-4.
- [21] Cavalheiro ETG, Brett CMA, Oliveira-Brett AM and Fatibello-Filho O. Bioelectroanalysis of pharmaceutical compounds. Bioanal. Rev. (2012) 4: 31-53.
- [22] Nussbaumer S, Bonnabry P, Veuthey JL and Fleury- Souverain S. Analysis of anticancer drugs: A review. Talanta (2011) 85: 2265-89.
- [23] Ghalkhani M and Shahrokhian S. Application of carbon nanoparticle/chitosan modified electrode for the square-wave adsorptive anodic stripping voltammetric determination of Niclosamide. Electrochem. Commun. (2010) 12: 66-9.
- [24] Shahrokhian S, Jokar E and Ghalkhani M. Electrochemical determination of piroxicam on the surface of pyrolytic graphite electrode modified with a film of carbon nanoparticle-chitosan. Microchim. Acta (2010) 170: 141-6.
- [25] Sharma VV, Gualandi I, Vlamidis Y and Tonelli D. Electrochemical behavior of reduced graphene oxide and multi-walled carbon nanotubes composites for catechol and dopamine oxidation. Electrochim. Acta (2017) 246: 415-23.
- [26] Mazloum-Ardakani M, Rajabzadeh N, Dehghani- Firouzabadi A, Benvidi A, Mirjalili BBF and Zamani L. Development of an electrode modified on the basis of carbon nanoparticles and reduced graphene oxide for simultaneous determination of isoproterenol, uric acid and tryptophan in real samples. J. Electroanal. Chem. (2016) 760: 151-7.
- [27] Tursynbolat S, Bakytkarim Y, Huang J and Wang L. Ultrasensitive electrochemical determination of metronidazole based on polydopamine/carboxylic multi-walled carbon nanotubes nanocomposites modified GCE. J. Pharm. Anal. (2018) 8: 124-30.
- [28] Gholivand MB, Ahmadi E and Haseli M. A novel voltammetric sensor for nevirapine, based on modified graphite electrode by MWCNs/poly(methylene blue)/ gold nanoparticle. Anal. Biochem. (2017) 527: 4-12.
- [29] Mohamed MA, Yehia AM, Banks CE and Allam NK. Novel MWCNTs/graphene oxide/pyrogallol composite with enhanced sensitivity for biosensing applications. Biosens. Bioelectron. (2017) 89: 1034-41.
- [30] El-Desoky HS, Ghoneim MM and El-Badawy FM. Carbon nanotubes modified electrode for enhanced voltammetric sensing of mebeverine hydrochloride in formulations and human serum samples. J. Electrochem. Soc. (2017) 164: B212-B222.
- [31] Cheraghi S, Taher MA and Karimi-Maleh H. A sensitive amplified sensor based on improved carbon paste electrode with 1-methyl-3-octylimidazolium tetrafluoroborate and ZnO/CNTs nanocomposite for differential pulse voltammetric analysis of raloxifene. Appl. Surf. Sci. (2017) 420: 882-5.
- [32] Sangamithirai D, Munusamy S, Narayanan V and Stephen A. Tunable poly(o-anisidine)/carbon nanotubes nanocomposites as an electrochemical sensor for the detection of an anthelmintic drug mebendazole. Polym. Bull. (2018) 75: 3127-47.
- [33] Asadian E, Shahrokhian S, Iraj Zad A and Ghorbani-Bidkorbeh F. Glassy carbon electrode modified with 3D graphene-carbon nanotube network for sensitive electrochemical determination of methotrexate. Sens. Actuat. B-Chem. (2017) 239: 617-27.
- [34] Khodadadian M, Jalili R, Bahrami MT and Bahrami G. Adsorptive behavior and voltammetric determination of hydralazine hydrochloride at a glassy carbon electrode modified with multiwalled carbon nanotubes. Iran. J. Pharm. Res. (2017) 16: 1312-9.
- [35] Karim-Nezhad G, Sarkary A, Khorablou Z and Dorraji PS. Synergistic effect of ZnO nanoparticles and carbon nanotube and polymeric film on electrochemical oxidation of acyclovir. Iran. J. Pharm. Res. (2018) 17: 52-2.
- [36] Mani V, Govindasamy M, Chen SM, Karthik R and Huang ST. Determination of dopamine using a glassy carbon electrode modified with a graphene and carbon nanotube hybrid decorated with molybdenum disulfide flowers. Microchim. Acta (2016) 183: 2267-75.
- [37] Shahrokhian S and Salimian R. Ultrasensitive detection of cancer biomarkers using conducting polymer/electrochemically reduced graphene oxide-based biosensor: Application toward BRCA1 sensing. Sens. Actuat. B-Chem. (2018) 266: 160-9.
- [38] Piovesan JV, Santana ER and Spinelli A. Reduced graphene oxide/gold nanoparticles nanocomposite-modified glassy carbon electrode for

- determination of endocrine disruptor methylparaben. *J. Electroanal. Chem.* (2018) 813: 163-70.
- [39] Vasilescu A, Ye R, Boulahneche S, Lamraoui S, Jijie R, Medjram MS, Gáspár S, Singh SK, Kurungot S, Melinte S, Boukherroub R and Szunerits S. Porous reduced graphene oxide modified electrodes for the analysis of protein aggregation. Part 2: Application to the analysis of calcitonin containing pharmaceutical formulation. *Electrochim. Acta* (2018) 266: 364-72.
- [40] Gao Y, Wu X, Wang H, Lu W and Guo M. Highly sensitive detection of hesperidin using AuNPs/rGO modified glassy carbon electrode. *Analyst* (2018) 143: 297-303.
- [41] AlAqad KM, Suleiman R, Al Hamouz OCS and Saleh TA. Novel graphene modified carbon-paste electrode for promazine detection by square wave voltammetry. *J. Mol. Liq.* (2018) 252: 75-82.
- [42] Nigović B, Jurić S and Mornar A. Electrochemical determination of nepafenac topically applied nonsteroidal anti-inflammatory drug using graphene nanoplatelets-carbon nanofibers modified glassy carbon electrode. *J. Electroanal. Chem.* (2018) 817: 30-5.
- [43] Tavakkoli N, Soltani N, Salavati H and Talakoub M. New carbon paste electrode modified with graphene/ TiO₂/V₂O₅ for electrochemical measurement of chlorpromazine hydrochloride. *J. Taiwan Inst. Chem. Eng.* (2018) 83: 50-8.
- [44] Uygun ZO, Şahin C, Yılmaz M, Akçay Y, Akdemir A and Sağın F. Fullerene-PAMAM(G5) composite modified impedimetric biosensor to detect Fetuin-A in real blood samples. *Anal. Biochem.* (2018) 542: 11-5.
- [45] Soltani N, Tavakkoli N, Mosavimanesh ZS and Davar F. Electrochemical determination of naproxen in the presence of acetaminophen using a carbon paste electrode modified with activated carbon nanoparticles. *C. R. Chim.* (2018) 21: 54-60.
- [46] Sathisha TV, Kumara Swamy BE, Schell M and Eswarappa B. Synthesis and characterization of carbon nanoparticles and their modified carbon paste electrode for the determination of dopamine. *J. Electroanal. Chem.* (2014) 720-721: 1-8.
- [47] Ghorbani-Bidkorbeh F, Shahrokhian S, Mohammadi Ali and Dinarvand R. Simultaneous voltammetric determination of tramadol and acetaminophen using carbon nanoparticles modified glassy carbon electrode. *Electrochim. Acta* (2010) 55: 2752-9.
- [48] Sudhakara Prasad K, Chuang MC and Annie Ho JA. Synthesis, characterization, and electrochemical applications of carbon nanoparticles derived from castor oil soot. *Talanta* (2012) 88: 445-9.
- [49] Yao S, Hua Y, Li G and Zhang Y. Adsorption behavior of ractopamine on carbon nanoparticle modified electrode and its analytical application. *Electrochim. Acta* (2012) 77: 83-8.
- [50] Sztó K, Joensson-Niedziolka M, Rozniecka E, Marken F and Opallo M. Direct electrochemistry of adsorbed proteins and bioelectrocatalysis at film electrode prepared from oppositely charged carbon nanoparticles. *Electrochim. Acta* (2013) 89: 132-8.
- [51] Shahrokhian S, Naderi L and Ghalkhani M. Nanocellulose/carbon nanoparticles nanocomposite film modified electrode for durable and sensitive electrochemical determination of metoclopramide. *Electroanalysis* (2015) 27: 2637-44.
- [52] Ghalkhani M and Shahrokhian S. Development of a Nanocellulose composite based voltammetric sensor for vitamin b9 analysis. *Curr. Nanosci.* (2016) 12: 493-9
- [53] Shahrokhian S, Ghalkhani M, Balotf H and Salimian R. Application of glassy carbon electrode modified with a carbon nanoparticle/melamine thin film for voltammetric determination of raloxifene. *J. Electroanal. Chem.* (2016) 780: 126-33.
- [54] Shahrokhian S, Ghalkhani M, Kohansal R and Mohammadi R. Biomimetic sensor for dobutamine employing Nano-TiO₂/Nafion/Carbon nanoparticles modified electrode. *Electroanalysis* (2015) 28: 970- 8.
- [55] Wong A, Santos AM and Fatibello-Filho O. Simultaneous determination of paracetamol and levofloxacin using a glassy carbon electrode modified with carbon black, silver nanoparticles and PEDOT:PSS film. *Sens. Actuat. B-Chem.* (2018) 255: 2264-73.
- [56] Smajdor J, Piech R, Ławrywianiec M and Paczosa- Bator B. Glassy carbon electrode modified with carbon black for sensitive estradiol determination by means of voltammetry and flow injection analysis with amperometric detection. *Anal. Biochem.* (2018) 544: 7-12.
- [57] Sornambikai S, Abdul Kadir MR, Kumar AS, Ponpandian N and Viswanathan C. Selective and low potential electrocatalytic oxidation and sensing of l-cysteine using metal impurity containing carbon black modified electrode. *Anal. Methods* (2017) 9: 6791-800.
- [58] Wong A., Scontri M., Materon E.M., Lanza M.R.V., Sotomayor M.D.P.T., Development and application of an electrochemical sensor modified with multi-walled carbon nanotubes and graphene oxide for the sensitive and selective detection of tetracycline, *Journal of Electroanalytical Chemistry* 757 (2015) 250–257.
- [59] Santos S.X.S., Cavaleiro Ê.T.G., Brett C.M.A., Analytical Potentialities of Carbon Nanotube/Silicone Rubber Composite Electrodes: Determination of Propranolol, *Electroanalysis* 2010, 22, No. 23, 2776 – 2783.
- [60] Aliakbarinodehi N., Micheli G.D., Carrara S., Optimized Electrochemical Detection of
- [61] Anti-Cancer Drug by Carbon Nanotubes or Gold Nanoparticles, 978-1-4799-8229-5/151/\$31.00 ©2015 IEEE.
- [62] Sikkander A.R.M., Vedhi C., Manisankar P., Electrochemical determination of calcium channel blocker drugs using multiwall carbon nanotube-modified glassy carbon electrode, *International Journal of Industrial Chemistry* 2012, 3:29.
- [63] Zhao X., Zhang Y., Gao D., Xiong H., Gao Y., Li S., Li X., Yang Z., Liu M., Dai J., Zhang D., Electrochemical Behavior and Determination of four drugs using Multi-Wall Carbon Nanotubes Modified Glassy Carbon Electrode, *Int. J. Electrochem. Sci.*, 14 (2019) 506 – 515, doi: 10.20964/2019.01.44.
- [64] Kazici H. Ç., Development of an ultra-sensitive method using nafion and multi-walled carbon nanotube coated glassy carbon electrode for atenolol determination, *Pamukkale Univ Muh Bilim Derg.*, 24(7), 1287-1292, 2018.
- [65] Kojabad R.N., Ebrahimias S., Pencil Graphite electrodes modified nano sensor for detection and determination of tramadol in blood serum, *QUID 2017*, pp. 597-604, Special Issue N°1- ISSN: 1692-343X, Medellín-Colombia.
- [66] Abbar J.C., Malode Sh.J., Nandibewoor Sh.T., Electrochemical determination of a hemorheologic drug, pentoxifylline at a multi-walled carbon nanotube paste electrode, *Bioelectrochemistry* 83 (2012) 1–7.
- [67] Kumar Y., Pramanik P., Das D.K., Electrochemical detection of paracetamol and dopamine molecules using nano-particles of cobalt ferrite and manganese ferrite modified, with graphite, *Heliyon* 5 (2019) e02031.
- [68] Khan A.A.P., Electrochemical Behavior and Determination of Amitriptyline Drug with MWCNT@ Cellulose Composite Modified Glassy Carbon Electrode, *Materials* 2020, 13, 1708; doi:10.3390/ma13071708.
- [69] Ashrafi A.M., Richter L., Preparation and Characterization of Carbon Paste Electrode Bulk-Modified with Multiwalled Carbon Nanotubes and Its Application in a Sensitive Assay of Antihyperlipidemic Simvastatin in Biological Samples, *Molecules* 2019, 24, 2215; doi:10.3390/molecules24122215.
- [70] Moscoso R., Alvarez-Lueje A., Squella J.A., Nanostructured interfaces containing MWCNT and nitro aromatics: A new tool to determine Nimesulide, *Microchemical Journal* 159 (2020) 105361.
- [71] Chipeture A.T., Moyo D.A.M., Shumba M., Multiwalled carbon nanotubes decorated with bismuth (III) oxide for electrochemical detection of an antipyretic and analgesic drug paracetamol in biological samples, *Chipeture et al. Journal of Analytical Science and Technology* (2019) 10:22.
- [72] Abdallah N.A., Carbon Nanotube Electrodes in Comparison to Coated Platinum Wire and Carbon Paste Selective Electrodes for the Determination of Tramadol Hydrochloride in Bulk Pharmaceutical Formulations and Spiked Human Plasma and Urine, *Sensors and Materials*, Vol. 28, No. 7 (2016) 797–816.
- [73] Abdel Ghani N.T., El-Nashar R.M., Hassan Sh.M., Carbon Nanotubes Modified and Conventional Selective Electrodes for Determination of Selegiline Hydrochloride and Its Pharmaceutical Preparations, *Int. J. Electrochem. Sci.*, 7 (2012) 7235 – 7252.
- [74] Khalil M.M., Farghali A.A., El-Rouby W.M.A., Abd-Elgawad I.H.,

Preparation and characterization of novel MWCNTs/Fe-Co doped TNTs nanocomposite for potentiometric determination of sulphuride in real water samples, *Scientific Reports* 10(8607),2020.

[75] Abdel-Haleem F.M., Gamal E., Rizk M.S., Madbouly A., El Nashar R.M., Anis B., Elnabawy H.M., Khalil A.S.G., Barhoum A., Molecularly

Imprinted Electrochemical Sensor-Based Fe₂O₃@MWCNTs for Ivabradine Drug Determination in Pharmaceutical Formulation, Serum, and Urine Samples, *Frontiers in Bioengineering and Biotechnology*, 2021 (9) 648704.

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