An Energy-Resolved Optical Non-invasive Device Detects Essential Electrolyte Balance in Humans at Point-of-Care

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Abstract

Regular monitoring of electrolyte balance is essential for patients suffering from chronic kidney disease (CKD), particularly those undergoing dialysis. In the context of the recent COVID-19 pandemic, more severe forms of infection are observed in elderly individuals and patients having co-morbidities like CKD. The repeated blood tests for the monitoring of electrolyte balance predispose them not only to COVID-19 but also other to hospital-acquired infections (HAI). Therefore, a non-invasive method for easy detection of essential electrolyte (K^+ and Na^+) levels is urgently needed. In this study, we developed an optical emission spectroscopy-based non-invasive device for simultaneous monitoring of salivary Na^+ and K^+ levels in a fast and reliable way. The device consisted of a closed spark chamber, micro-spectrometer, high voltage spark generator, electronic circuits, optical fiber, and an indigenously developed software based on the LabVIEW platform. The optical emission originating from the biological sample (i.e., saliva) due to recombination of ions energized by impingement of electrons returning from high voltage spark provides necessary information about the concentration of electrolytes. A small-scale clinical trial on 30 healthy human subjects shows the potential of the indigenously developed device in determining salivary Na^+ and K^+ concentration. The low-cost, portable, point-of-care device requires only 2 mL of sample, and can simultaneously measure 1.0–190.0 mM Na^+ , and 1.0–270.9 mM K^+ . To our understanding, the present work will find its relevance in combating COVID-19 morbidities, along with regular CKD patient-care.

Keywords Non-invasive essential electrolyte measurement · Spectroscopic instrument · CKD management

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Introduction

The SARS-CoV-2 virus which causes the COVID-19 infection has immensely impacted the world and caused a global pandemic with over 91 million infections and over 1.9 million fatalities till January 2021 (JHU 2021). Patients, especially those with kidney transplants, cardiovascular diseases, and diabetes are at high risk of COVID-19 infection. Moreover, patients undergoing hemodialysis have to visit medical centers frequently, thereby loses their ability to self-isolate and become prone to nosocomial infections (Ajaimy and Melamed 2020). While looking at the pathophysiology of COVID-19, many researchers are focusing attention on a specific protein, namely, Angiotensin-Converting Enzyme 2 (ACE 2) that aids the virus to infect the human cells. The spike protein on the surface of the SARS CoV-2 virus attaches to ACE 2 for their entry to human cells and replicates to spread infection. This becomes lethal for patients having chronic kidney diseases (CKD). ACE 2-inhibition

by the virus also leads to vasoconstriction increasing blood pressure and causes hyponatremia leading to water retention in the body resulting in electrolyte imbalance in humans (Behl et al. (2020); Mizuiri and Ohashi 2015; Soler 2013). The relative expression of ACE and ACE 2 synergistically controls the electrolyte balance (Wakahara 2007; Pinheiro 2019; Rieder 1999). In CKD patients, disruption in the balance between intra-renal ACE and ACE 2 expression gives rise to high levels of angiotensin 2, contributing to the progression of renal damage (Hamming 2007). Thus, necessary diagnostic information for the treatment of several diseases like CKD, acute cardiac arrhythmias hypertension, etc. is determined based on the analysis of the vital electrolyte levels, especially sodium (Na^+) and potassium (K^+) in the human body (Garcia 1992). In this context, Hyponatremia, another very common electrolyte disorder, especially in the elderly, is associated with significant morbidity, mortality, and disability in the context of the COVID-19 pandemic. Thus, easy access to the essential electrolyte monitoring (preferably at home) in a non-painful way is essential to control the comorbidity of CKD and elderly subjects in the context of the COVID-19 pandemic (Fraser and Blakeman 2016).

Despite being the most familiar analytes, very few techniques are available for the measurement of Na^+ and K^+ in clinical chemistry laboratories. Ion-selective electrodes (ISEs), flame photometry, and atomic absorption spectrometry (AAS) are the conventional technologies for quantifying the essential ion levels in plasma or other biological fluids (Giavarina 2019; Rose 2014; Lee 2019; Delanghe 2019). Although ISEs, AAS, and flame photometry are used extensively, some limitations exist. High cost, immobility, utilization of various chemical reagents, use of dedicated electrodes for each electrolyte, the requirement of an expert operator, are a few to mention (Durst 1978; Delves 1987; Diwakar and Kulkarni 2012). These drawbacks make it difficult to use the aforementioned methodologies in point-of-care diagnostics, which is vital for the current healthcare situation. Depending on the type of instrument, the sample is selected from urine, saliva, and whole blood. Extraction of blood by pricking needles is not only painful but also has the risk of excessive bleeding, infection, pain, loss of consciousness, and multiple hospital visits which may cause Hospital Acquired Infections (HAI) (Zungu et al. 2008). Thus, low-cost non-invasive techniques for the detection of electrolyte levels from other biological fluids, are preferred. A recent study from our group used a spark emission spectroscopy-based method for the detection of electrolyte levels from the human blood serum (Halder 2019). However, no detailed study using other body fluids was performed. Moreover, the method required a great volume of sample for detection which makes it a bit difficult for clinical diagnosis at point-of-care. In this study, we have successfully

lowered the minimum detectable Na^+ level to 1 mM from 100 mM. Installation cost and cost per sample test have been decreased to a substantial amount. Thus, the primary objective of the present work is to develop a non-invasive, portable device that would be able to detect the concentration of electrolyte contents in humans at point-of-care using the wash of oral cavity without a rigorous sample preparation procedure.

Materials and Methods

Instrumental Setup

Figure 1a schematically describes the detailed arrangement of the device, which includes a closed spark chamber (CSC), vaporizer, micro-spectrometer, high voltage control electronics, optical fibers, and an indigenously developed software. Figure 1b, c show the digital photographs of the prototype device. The CSC, a metal tube of 1.9 cm diameter, comprises two opposing copper electrodes (standard spark plug, Model- CPR8EA-9, NGK Spark Plug India Pvt. Ltd., India) having a 0.1 cm distance in between (Fig. 1a) for spark discharge (Staack 2008; Singh 2014; Hnatiuc et al. 2011; Sher et al. 1992; Shrivastava and Gupta 2011). Intending to reduce the manufacturing cost, we used commercially available copper electrodes having a very low corrosion rate instead of noble metal electrodes. The low corrosion rate ensures no possible interference with optical observations to occur. The CSC also hosts a multimode optical fiber (numerical aperture: 0.10; core: 10.5 cm; Thor Labs, USA) placed at a right angle to the spark plug at a distance of 0.85 cm from the center to carry the optical information to the micro-spectrometer. The micro-spectrometer was developed using a MEMS-based chip from Hamamatsu Photonics, Japan (Model: C12880MA). The high voltage electronics include a transformer that supplies the required voltage to generate a spark. The vaporizer breaks the liquid sample into small aerosol droplets and pushes them to the CSC.

Working Principle

The working principle remained the same as our previous study (Halder 2019). The major modification in the setup i.e., closing the spark chamber resulted not only in the requirement of less amount of sample but also reduction of fluctuations. In brief, spark plugs in the CSC generate plasma utilizing high voltage sources and excite the vaporized samples (i.e., aqueous solutions of electrolytes, or biological fluids). The optical emission originating from each sample (i.e., optical plume, Fig. 2a) due to recombination of ions energized by impingement of electrons resulting from high voltage plasma discharge is collected by using the

Fig. 1 a The schematic of the experimental arrangement for non-invasive detection of essential electrolytes in humans. b, c The digital photographs of the prototype device

optical fiber setup and detected by the micro-spectrometer. The control of the system including interfacing and IoT strategy is executed by an indigenously developed software in the LabVIEW platform (National Instruments, USA).

Calibration of the Device

For calibration of the instrument, different concentrations of sodium chloride (NaCl; Sigma, USA) and potassium chloride (KCl; Sigma, USA) solutions were prepared using Millipore water. The concentrations of NaCl used were 25, 50, 75, 100, 150, and 200 mgL⁻¹. While for KCl, the concentrations were 50, 75, 100, 150, and 200 mgL⁻¹. The chemicals were of the highest commercially available grade and used without further purification.

For measurement, a 2 mL solution was placed in the sterilized sample holder and subsequently measured using the principle stated in the previous section. Instrument index value (i.e., the emission intensity corresponding to the emission peaks of Na⁺, and K⁺ ions) was obtained for each calibrating sample and finally correlated with the known concentrations to obtain the calibration equations which were included in the software (vide infra). In between two consecutive sets of measurements, the spark plugs were turned on for 25 min to clean the electrodes and avoid possible contamination among samples.

Fig. 2 **a** The high voltage electrodes generating the spark. **b** The spectrum where the individual peaks for Na⁺ and K⁺ can be seen. **c, d** Show the calibration curves obtained for Na⁺ and K⁺ with $\pm 5\%$ error, respectively

Validation of the Device using Biological Fluids

Study Population and Ethical Considerations

The study was conducted following the guidelines approved by the Institutional Ethics Committee (Ref: CREC-STM/2018-AS27, dated 29.12.2018). All studies involving human subjects were performed according to the guidelines of the Declaration of Helsinki (Declaration 2014) and Indian Council for Medical Research (ICMR), Govt. of India.

As a proof-of-concept study, the sample size was estimated to be 30. Written informed consent was obtained from the volunteers who agreed to participate in the study after understanding the particulars and consequences of the study. All data and information about the subjects are kept confidential and utilized only for this study.

Sample Collection

After preliminary mouthwash with regular water, 4 mL of deionized water was poured into the oral cavity of the subject. After one minute, the water mixed saliva i.e., the sample (~4.5 mL) was collected. 1.5 mL of the collected sample was diluted with 0.5 mL of deionized water, placed into the sterilized sample holder, and subsequently measured using the method described in the earlier section. From the instrument index values, respective concentrations of the ions were obtained according to the calibration equations. Multiplying the obtained values with proper dilution factor provided actual levels of Na⁺ and K⁺ in the saliva.

Statistical Analysis

Data are expressed as Mean $\pm$ Standard Deviation (SD) unless otherwise stated. All statistical analyses including linear, and non-linear regression were performed using Origin Pro 8.5 (Origin Lab, USA). For reference interval calculations we used the parametric method considering the Gaussian distribution of the values. The difference between study results and reference standards was estimated using an unpaired *t* test (GraphPad Prism 9.0, GraphPad Software, USA). *P* < 0.05 were considered significant.

Results and Discussion

In the present study, we used the energy-resolved optical emission signatures associated with Na⁺ and K⁺ for the determination of their respective concentrations in the samples of interest. Figure 2b shows the emission spectral pattern of the electrolytes. The observed peaks at 589 and 824 nm corresponds to Na⁺ and K⁺, respectively (Slanger and Osterbrock 2000). As stated in the methods section, calibration curves were obtained using different concentrations of Na⁺ and K⁺ solutions. As evident from Fig. 2c, d, emission intensities were linearly dependent upon the electrolyte concentrations for both Na⁺ and K⁺. Linear regression analysis leads to the following calibration equations with adj. *R*² of 0.999 (Na⁺), and 0.988 (K⁺).

$$\text{Intensity}_{\text{Na}^+}(\text{counts}) = 23.31 + 20.82 \text{ Concentration}_{\text{Na}^+}(\text{mEq/L}) \quad (1)$$

$$\text{Intensity}_{\text{K}^+}(\text{counts}) = -2.29 + 19.5 \text{ Concentration}_{\text{K}^+}(\text{mEq/L}) \quad (2)$$

where, Intensity i.e., instrument index value refers to the optical emission intensities (counts) of the electrolytes at their respective peaks, and concentration refers to the concentration of the samples in the holder. The calibration equations served as standard curves and were incorporated into the software to calculate electrolyte concentrations of unknown samples from their emission intensities.

Next, we aimed to quantify Na⁺ and K⁺ concentrations from salivary samples. Salivary glands are non-excitable effector organs in which appreciable translocation of fluid and electrolytes occurs from the interior of the organism to the outside, usually in response to the neural stimulation (Schneyer et al. 1972). The salivary secretion does not regulate the body's electrolyte balance, rather functions as an indicator to it. It is even considered a better physiological marker of electrolyte imbalance than the serum or blood. Despite having huge potential as a disease marker, the salivary electrolyte levels received less attention in medical diagnosis due to the unavailability of standardized measurement techniques in clinical chemistry laboratories. The first hurdle in measuring electrolyte concentration from saliva

Fig. 3 a The volume of salivary secretion collected at different time intervals (60–120 s). b, c Respectively show the salivary Na⁺ and K⁺ concentration during this period

was to standardize the sample collection protocol. Here, we used a non-stimulated method by washing the oral cavity with 4 mL of deionized water for 60 s. The comprehensive wash of the oral cavity for 60 s is expected to overcome the physiological factors on which salivation depends. As showed in Fig. 3a, the volume of salivary secretion by this method reached a stable condition between 60 and 120 s. The salivary Na⁺ or K⁺ concentration also remained nearly constant during this period (Fig. 3b, c). Furthermore, < 60 s

Fig. 4 **a** The individual Na⁺ levels of 30 subjects. **b** The statistical analysis of the same

is too little to monitor for the patients suffering from acute illness. Therefore, the washing time was set at 60 s.

Figure 4a shows the salivary Na⁺ values of each patient obtained using our device. As all the volunteers were healthy in terms of electrolyte balance, we plotted a frequency distribution curve for salivary Na⁺ concentration (Fig. 4b) to estimate the reference range for the study population. The observed frequency distribution curve for salivary Na⁺ levels showed a bell-shaped pattern (i.e., Gaussian distribution) indicating normal distribution, one of the major criteria for reference range determination. The central tendency (i.e., mean) was found to be 17.5 mEqL⁻¹, with a 2SD of 2.7 mEqL⁻¹ (i.e., full-width-half-maxima of the frequency distribution plot). As per definition, the reference range for a given population for a given parameter (i.e., analyte or measurand) ranges from Mean + 2SD to Mean - 2SD. It is expected that 95% of the individuals if tested, will have their analyte values within this range. Thus, in our case, the reference range for salivary Na⁺ was found to be 14.8 mEqL⁻¹ (lower limit of variation) to 20.2 mEqL⁻¹ (upper limit of variation).

Fig. 5 **a** The individual K⁺ levels of 30 subjects. **b** The statistical analysis of the same. The inset shows the correlation of the K⁺ levels from saliva and blood plasma as obtained from the reported data (Horiba 2017)

The calculated limits of variation were in good agreement with the published limits of salivary Na⁺ concentration (26.4 ± 11.8 mEqL⁻¹). It is worth mentioning here that, if the population is healthy and the instrument provides accurate measurements, a frequency distribution curve, would tend to have the same general shape if the number of population is increased, or if the groupings were varied to some small degree (White 1955; Chiles et al. 1996). Therefore, the observed statistically insignificant difference between the frequency distribution curve obtained from the developed device and previously published values, in turn, indicates the efficacy of the device in clinical settings.

Figure 5a shows the salivary K⁺ levels of the 30 healthy volunteers who participated in the study. Figure 5b shows the frequency distribution curve. Similar to Na⁺, the frequency distribution curve for salivary K⁺ levels were found to be bell-shaped. The central tendency was 27.2 mEqL⁻¹, with a 2SD of 2.7 mEqL⁻¹. The reference range for salivary K⁺ was calculated to be 25.5 mEqL⁻¹ (lower limit of

variation) to 28.9 mEqL^{-1} (upper limit of variation). The observed limits of variation showed no significant difference from the previously published reference range which is $19.7 \pm 3.9 \text{ mEqL}^{-1}$. Therefore, the salivary K^+ concentrations measured by the developed device efficiently mimicked corresponding clinical values, indicating the efficiency of the instrument in clinical settings.

Previous studies have revealed that in both hypotonic and isotonic human saliva the concentration of Na^+ ions is less compared to serum, while K^+ concentration is frequently higher than the serum level of this ion. In our study too, we observed similar results. The salivary Na^+ level found in our study is ~ 8 times lower than that found in serum. Similarly, the salivary K^+ concentration in this study is ~ 7 times higher compared to serum. The higher concentration of Na^+ observed in the blood could be due to the higher volume and surface area of blood (Wankasi 2019). Moreover, blood is an extracellular fluid from where a lot of nutrients and electrolytes are cleared out from the body or transported to other cells, tissues, and body fluids for systemic sustenance (Wankasi 2019). On the other hand the high concentration of K^+ in saliva is due to the filtration of potassium into the saliva and the active release to the saliva by nerves stimulation as reported by Carlos et al. (Labat 2018). Also, Na^+ ions are actively reabsorbed from all the salivary ducts and K^+ ions are actively secreted in exchange for the Na^+ (Wankasi 2019). Therefore, the Na^+ ion concentration of the saliva becomes greatly reduced, while the K^+ ion concentration becomes increased. Figure 5b-inset shows a sample correlation between serum and salivary concentration of K^+ (Horiba 2017). However, we found no authentic report that established a similar correlation between serum and salivary Na^+ concentration. Therefore, a detailed large-scale systemic clinical study is required to find the exact correlation between serum and salivary electrolytes, which we are planning to do in the future.

It is worth mentioning here, the salivary electrolyte concentration is very much dependent on circadian rhythm. It also varies greatly depending upon the time of daily meal intake. We have measured the salivary electrolyte concentrations at different times of the day and observed the variation as depicted in Fig. 6. However, for maintaining uniformity, we collected all the samples used for the determination of the reference range at fasting conditions. This kind of strategy is often used while measuring certain blood parameters to avoid diurnal variations.

This is a very preliminary proof of concept study, the sole aim of which was to test whether the newly developed device can measure salivary Na^+ and K^+ concentration from the mouth wash as an alternative to the conventional invasive electrolyte detection techniques. Previously, we also proposed a device with the same working principle for the detection of analytes from blood samples. Here, the

Fig. 6 Measured salivary electrolyte concentrations at different times of the day

installation and maintenance cost, and amount of sample required for testing have been reduced to a remarkable extent compared to our previously proposed device. Due to covered CSC, and more integrated systems the proposed device causes no known medical hazard since no chemical or biomedical waste is exhausted (unlike our previous design) to the surroundings. Moreover, it helped to lower the minimum detection limit for Na^+ to 1 mM, which adds to its clinical significance. Table 1 depicts a detailed comparative analysis of our proposed device with other standard devices and our previous design.

There are some limitations of the study, which lay the foundation stone for future investigations. First of all, we restricted our study to only normal volunteers since we did not have ethical permission to work on the patients, particularly the COVID-19 infected ones. It is of particular concern whether cough and cold could affect our measurements or salivary electrolyte levels. But, previous studies have demonstrated that although cough and cold alter several other salivary contents like expelled nucleic acid, glucose, protein, and digestive enzyme (e.g., amylase) levels, it has little implications on the secreted electrolytes (Farzan 1990). Therefore, we can assume that our method will also be suitable for those patients. Another drawback of this study is that due to ethical issues we could not measure electrolyte levels in other biological fluids like sweat, or urine. Theoretically, there is no apprehension in measuring electrolyte levels of other biological fluids, but experimentally it needs to be checked. A reference range of Na^+ and K^+ has to be determined for each of the biological fluids for the inclusion of this technique in regular clinical practices. A more comprehensive large scale clinical study will follow this work to answer the clinical issues in details.

Table 1 Comparative analysis of our proposed device with few other standard devices and our previous design

Type	ISE	ABG	ICP-OES	OES	OES
Device	AU480 chemistry analyzer, Beckman Coulter Inc., USA	OPTI® CCA-TS2, OPTI Medical Systems Inc., USA	Optima 7300 V PerkinElmer, Inc. Shelton, CT, USA	NaLiK	Proposed technique
Measurement principle	Spectrophotometry and potentiometry	Optical fluorescence and reflectance	Inductively coupled plasma-optical Emission spectroscopy (ICP-OES)	Optical emission spectroscopy	Optical emission spectroscopy
Sample type	Demonstrated in serum or plasma, urine and other fluids (AU480 Chemistry Analyzer)	Demonstrated in whole blood, serum or plasma (OPTI® CCA-TS2)	Demonstrated in human milk (Geddes and Perrella 2019)	Serum or plasma	Wash from mouth cavity
Sample volume	1.0–25 mL	125 mL	50 mL	10–500 mL	2 mL
Calibration time	< 60 s	< 90 s	< 90 s	< 60 s	< 40 s
Measurement time	< 120 s	< 120 s	< 90 s	< 90 s	~ 37 s
Operating temperature	18–32 °C	10–30 °C	15–35 °C	15–37 °C	15–47 °C
Measurement range	Na ⁺ 90–200 (mM) K ⁺ 1.9–9.93 (mM)	100–180 (mM) 0.8–9.99 (mM)	2.59–21.50 (mM) 7.91–15.20 (mM)	100–320 (mM) 1.0–9.95 (mM)	1.0–190.0 (mM) 1.0–270.9 (mM)
Display resolution (low/high)	Na ⁺ 1/0.1 K ⁺ 0.1/0.01	1/0.1 0.1/0.01	0.1/0.01 0.1/0.01	0.1/0.01 0.1/0.01	0.1/0.01 0.1/0.01
Installation cost (approx.)	39,513.15 USD	4324.05 USD	38,012.65 USD	1153.08 USD	1000.00 USD
Test cost (per sample)	Between 4.90 and 11.82 USD	Between 4.90 and 11.82 USD	Between 4.90 and 11.82 USD	1.44 USD	0.65 USD
Maintenance cost	High	High	High	150 USD/5 year	50 USD/5 year
Flexibility of use in different ambience	Laboratory settings	Laboratory settings	Laboratory settings	Portable	Portable
Manpower to operate	One trained technician	One trained doctor	One trained technician	One trained paramedical staff	No expertise
Medical safety	Chances of biomedical waste	Chances of biomedical waste	Chances of biomedical waste	Chances of biomedical waste exposure to air	No medical hazard; No chemical exhaust

Fig. 7 Advantages of the developed techniques

Conclusion

In the present work, we have developed a non-invasive technique for the detection of essential electrolyte levels in human subjects using optical emission spectroscopy from samples collected from the wash of the mouth cavity. We have also developed a user interfacing software in the LabView platform to acquire the optical signals and to calculate the electrolyte concentration instantaneously. The technique has been validated through a small-scale clinical trial on 30 healthy volunteers. The obtained values of Na^+ and K^+ concentrations are found to be consistent with that of the reported values. The advantages of the developed system over the conventional blood sample-based technique include real-time analysis of the data, painless, needle-free sample collection and IoT-enabled e-healthcare strategy as remarkable as shown in Fig. 7. To our understanding, the co-morbidity of CKD and elderly patients due to frequent hospital visits and immune-compromised conditions can be managed in the COVID-19 pandemic situation through the developed device. A large-scale clinical study will be followed to address the clinical issues in further detail. Since our study was restricted with limited ethical permission, we are aiming to do further studies using other biological fluids, such as urine and sweat samples.

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Author contributions NB developed the instrument, and was involved in the planning of the study; coordinated data collection carried out the primary analyses, and drafted an initial manuscript. SS developed the software and revised the manuscript. AH was involved in the design and development of the instrument and reviewed the manuscript. AA

analyzed the data, interpreted it, and revised the manuscript. RG made a substantial contribution to data acquisition and interpretation. DS helped in the design and development of the device. SKT, AKM, and PM planned the study interpreted the data, and reviewed the manuscript. SKP conceptualized and planned the study, interpreted the data, and revised the manuscript.

Data availability The datasets generated for this study are available on legitimate request to the corresponding author.

Compliance with ethical standards

Conflicts of interest There are no conflicts to declare.

References

- Ajaimy M, Melamed ML (2020) COVID-19 in patients with kidney disease. *Am Soc Nephrol* 15(8):1087–1089
- AU480 Chemistry Analyzer, <https://www.beckmancoulter.com/products/chemistry/au480>.
- Behl T et al (2020) The dual impact of ACE2 in COVID-19 and ironical actions in geriatrics and pediatrics with possible therapeutic solutions. *Life Sci* 15:118075
- Chiles V et al (1996) Principles of engineering manufacture, 3rd edn. Butterworth-Heinemann. ISBN 0080539610
- Declaration H (2014) World Medical Association Declaration of Helsinki. Retrieved Jan, 2014. 22:2014.
- Delanghe JR (2019) Management of electrolyte disorders: also the method matters! *Acta Clin Belg* 74(1):2–6
- Delves H (1987) Atomic absorption spectroscopy in clinical analysis. *Ann Clin Biochem* 24(6):529–551
- Diwakar PK, Kulkarni P (2012) Measurement of elemental concentration of aerosols using spark emission spectroscopy. *J Anal At Spectrom* 27(7):1101–1109
- Durst RA (1978) Sources of error in ion-selective electrode potentiometry in ion-selective electrodes in analytical chemistry. Springer, New York, pp 311–338
- Farzan S (1990) Cough and sputum production, in *Clinical Methods: the History, Physical, and Laboratory Examinations*. 3rd edn. Butterworths.
- Fraser SD, Blakeman T (2016) Chronic kidney disease: identification and management in primary care. *Pragmatic Observ Res* 7:21
- Garcia RP et al (1992) Serum analysis for potassium ions using a fibre optic sensor. *Clin Chim Acta* 207(1–2):31–40
- Geddes D, Perrella S (2019) *Nutrients* 11:802
- Giavarina D (2019) Blood biochemistry: measuring major plasma electrolytes critical care nephrology. Elsevier, Philadelphia, pp 320–322
- Halder A et al (2019) NaLiK, an self-developed device for rapid, reliable and simultaneous assessment of sodium, lithium and potassium for management of fluid balance and bipolar disorder in human subjects. *J Anal At Spectrom* 34(9):1875–1881
- Hamming I et al (2007) The emerging role of ACE2 in physiology and disease. *J Pathol* 212(1):1–11
- Hnatiuc B et al (2011) Spectroscopic diagnostic of transient plasma produced by a spark plug. *Rom J Phys* 56(SUPPL):109–113
- Horiba (2017) Monitoring potassium levels in human saliva for mitigating periodic paralysis. *Laqua twin* 2403
- Johns Hopkins University (JHU) (2021) COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU). Johns Hopkins University (JHU). <https://coronavirus.jhu.edu/map.html>

- Labat C et al (2018) Differential associations for Salivary Sodium, Potassium, Calcium, and Phosphate levels with Carotid Intima media thickness, heart rate, and arterial stiffness. *Dis Markers* 2018:3152146
- Lee J et al (2019) An integrated ion-selective optode sensor cartridge for directly detecting electrolyte ions in blood plasma without pretreatment to adjust pH. *Sens Actua B Chem* 280:256–262
- Mizuiiri S, Ohashi Y (2015) ACE and ACE2 in kidney disease. *World J Nephrol* 4(1):74
- OPTI® CCA-TS2 Blood Gas and Electrolyte Analyzer, <https://www.optimedical.com/products-services/opti-CCATS2.html>.
- Pinheiro DS et al (2019) The combination of ACE I/D and ACE2 G8790A polymorphisms reveals susceptibility to hypertension: a genetic association study in Brazilian patients. *PLoS ONE* 14(8):e0221248
- Rieder MJ et al (1999) Sequence variation in the human angiotensin converting enzyme. *Nat Genet* 22(1):59–62
- Rose DP et al (2014) Adhesive RFID sensor patch for monitoring of sweat electrolytes. *IEEE Trans Biomed Eng* 62(6):1457–1465
- Schneyer LH, Young JA, Schneyer CA (1972) Salivary secretion of electrolytes. *Physiol Rev* 52(3):720–777
- Sher E et al (1992) A corona spark plug system for spark-ignition engines. *SAE Technical Paper*.
- Shrivastava A, Gupta VB (2011) Methods for the determination of limit of detection and limit of quantitation of the analytical methods. *Chron Young Sci* 2(1):21
- Singh S et al (2014) Spark spectrometry of toxic smokes: towards a portable, inexpensive, and high-resolution environment monitoring instrument. *Clean Technol Environ Policy* 16(8):1703–1712
- Slanger T, Osterbrock D (2000) Investigations of potassium, lithium, and sodium emission in the nightglow and OH cross calibration. *J Geophys Res* 105(D1):1425–1429
- Soler MJ et al (2013) Angiotensin-converting enzyme 2 activity in patients with chronic kidney disease. *Nephrol Dial Transplant* 28(11):2687–2697
- Staack D et al (2008) Nanoscale corona discharge in liquids, enabling nanosecond optical emission spectroscopy. *Angew Chem* 120(42):8140–8144
- Wakahara S et al (2007) Synergistic expression of angiotensin-converting enzyme (ACE) and ACE2 in human renal tissue and confounding effects of hypertension on the ACE to ACE2 ratio. *Endocrinology* 148(5):2453–2457
- Wankasi MM et al (2019) Glucose and electrolytes concentrations in blood and saliva samples amongst diabetics. *J Diabet Mellit* 9(2):39–49
- White AG et al (1955) Physiological and pharmacological regulation of human salivary electrolyte concentrations; with a discussion of electrolyte concentrations of some other exocrine secretions. *J Clin Investig* 34(2):246–255
- Zungu LI, Sengane M, Setswe KG (2008) Knowledge and experiences of needle prick injuries (NPI) among nursing students at a. *South African Family Pract* 50(5):48–48

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