

LAB-ON-PAPER ELECTROANALYTICAL DEVICES: TOWARDS THE FULLY INTEGRATION OF STEPS

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1.- Objectives

There is a marked trend towards decentralization of analysis. It is an urgent requirement in environmental, food, clinical or other fields of analysis. This is the moment to include a new milestone in the timeline of Analytical Chemistry. Our discipline is becoming bifid: complicated and expensive high-tech equipment is living together with low-cost and simple devices for doing the same thing, that is performing analytical processes. On the one hand, current difficult problems require exquisite sophistication in the instruments and methodologies but, at the same time, the use of drones in environmental monitoring, the urge for fruit analyses after post-harvest treatments or the occurrence of episodes such as stroke are some of the examples that will require point-of-use devices.

Paper can undoubtedly play a main role in this scenario. Properties and benefits are well known. Remarkable are the possibility of fluid flowing by capillary forces, the ability to store functional materials or the integration with several detection schemes. Among them, the electrochemical detection fits perfectly with decentralization purposes. All the advantages make this material perfect for the integration of several steps of the analytical process to generate simple but sample-to-result lab-on-paper analytical devices.

2.- Methods

In this context, several devices that integrate different steps of the analytical process are here presented. Sampling or diluting is performed with simple microfluidic tongues; separation by electrophoresis is done with a paper microchip; enzymatic reactions, exemplified by glucose determination, are carried out on multiplexed biosensors; immunoassays can be performed in vertical or lateral flow formats and detection can adopt different approaches. Carbon or metal can be the basis of the electrodes, used as films directly on paper or using unconventional elements such as pins or staples. Using nanomaterials as well as taking advantage of preconcentration strategies, provides with interesting and promising approaches for decentralized analysis.

3.- Results

In Fig. 1, there are some examples of paper-based platforms including different steps of the sample-result process. A microfluidic sampler allows avoiding the use of micropipettes for adding the solutions onto a carbon-based paper platform (Fig. 1A). Several working areas can be measured simultaneously, as depicted in Fig. 1C, if a multipotentiostat is employed. Selectivity is an important issue that can be approached in two different ways: i) using bioreagents or ii) integrating separation techniques. Then, paper was wax-printed and diffused to generate channels for electrophoretic separation. Folding the paper allowed the creation of functional layers for: i) injection, ii) separation and iii) detection (Fig. 1B). Alternatively, biocatalysts (enzymes) or affinity reagents (antibodies) can be also incorporated for selective methodologies. Regarding the detection, sputtered or wire metals can be employed for detection but carbon ink is the most common. This advantageous material can be added directly on paper but off-paper electrodes are also possible. Miniaturised electrochemical thick or thin layers can be combined for detection but also unconventional elements as pins or staples (Fig. 1D). Sensitivity can be increased through the electrode nanostructuring and also combination with preconcentration strategies.

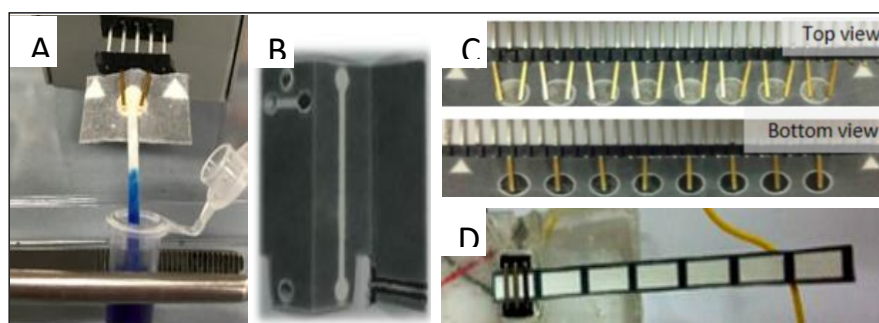


Fig. 1: Examples of: A) microfluidic tongue acting as sampler for electroanalytical detection [1], B) multi-layered electrophoresis microchip [2], C) top and bottom views of a multiplexed electrochemical glucose sensor [1] and D) staple-based electrochemical platform for paper substrates [3].

4.- Conclusions

Paper-based electroanalytical devices have demonstrated to be very useful for decentralized analysis in very different areas: environmental, food or clinical fields. Several examples with integration of different steps and approaches are presented. The combination is required for obtaining a sample-to-result platform that could be further coupled with the other elements: e.g., energy source or instrumentation and control systems, to have a real-world useful device.

Keywords: Paper-based devices, Electroanalysis, Lab-on-paper platforms, Low-cost analysis.

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