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Dipstick color recognition in dry chemical urinalysis: A mini review

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Highlights

This review presents four urinalysis methods, the naked-eye method, the integrating sphere method, the color sensor method and the image sensor method, based on color recognition technology, and discusses the techniques of each method.

Abstract

Urinalysis is an essential diagnostic tool for urinary tract infections, kidney disease, diabetes, and other clinical conditions. Dipsticks, which allow for quick screening of urine specimens, are used in the clinic settings to identify the presence and concentration of labeled substances such as urine pH, urine protein, urine glucose, urine ketone, and urine nitrite. This paper reviews four urine dry chemical analysis methods, which are based on human eyes, integrating sphere, color sensors, and image sensors, respectively. The techniques of each method are also discussed.

Keywords: Urinalysis, dry chemical analysis, color recognition, RGB color sensor, image sensor

Introduction

As a laboratory test, urinalysis is an essential diagnostic tool for kidney disease, urinary tract infections, and diabetes, which are highly prevalent diseases in clinic [1-3]. Urinalysis is the most common medical test performed on urine specimens, and the methods for urine composition analysis include physical analysis, formed element analysis, and dry chemical analysis [4].

Physical analysis of urine is the direct visual observation of urine with eyes and/or nose, such as its quantity, turbidity, color, and odor. Taking urine turbidity as an example, it may be clear, cloudy, turbid, or layered, all of which are observable with human eyes. Microscopy can be employed for the physical analysis of urine, enabling the differentiation of components such as red blood cells, white blood cells, epithelial cells, casts, crystals, sperms, and mucous threads.

Formed element analysis is performed on urine sediments that contain cells (red blood cells, white blood cells, epithelial cells, fat oval bodies), casts (cellular casts with cells inside, and noncellular casts with hyaline, granular, waxy, and fatty shapes), crystals (normal and abnormal), organisms (bacteria, yeast cells), and others such as sperms. Formed elements analysis is usually conducted using a flow cytometer and an impedance sensor.

Urine dry chemical analysis uses dipsticks, also called reagent strips, to identify the presence and concentration of labeled substances based on color recognition [5]. Urine dry chemical analysis is crucial for clinical diagnosis since it keeps track of the patient's state, which assists the physician in formulating treatment plans. It also aids disease screening and enables hospitals to conduct high-volume-sample testing. As the currently most used test in urine composition analysis, dry chemical analysis acquires the relevant test findings by recognizing the color of the test items. Chemical analysis of urine includes urine specific gravity, urine pH, urine leukocytes, urine nitrite, urine protein, urine glucose, urine ketone, urobilinogen, urine biliru-

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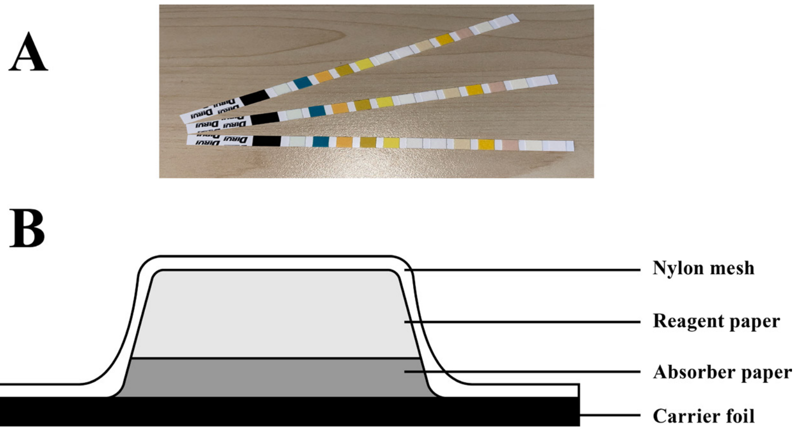

Figure 1. Urine dipsticks and structure of a reagent pad. (A) Urine dipsticks; (B) Structure of a reagent pad.

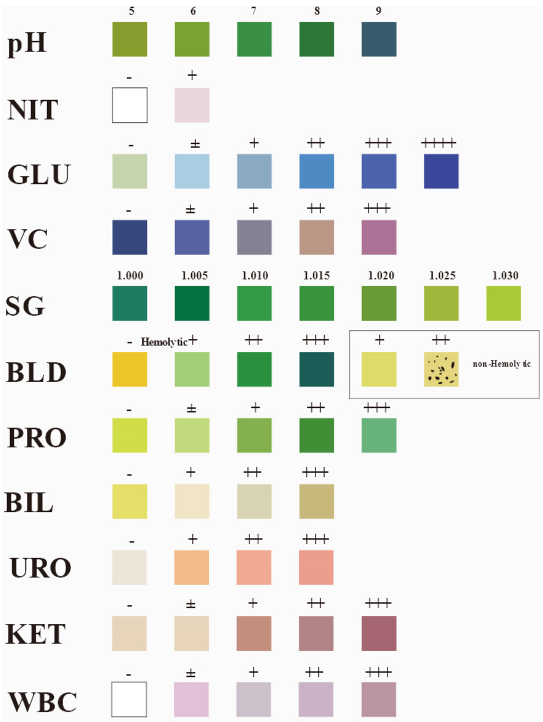

Figure 2. Color chart of an 11-pad reagent dipstick. pH, Urine pH; NIT, urine nitrite; GLU, urine glucose; VC, ascorbic acid; SG, specific gravity; BLD, urine blood; PRO, urine protein; BIL, urine bilirubin; URO, urobilinogen; KET, urine ketone; WBC, white blood cell.

bin, urine blood and so on [4, 6].

This a mini review summarizes multiple newly developed techniques in urine dry chemical analysis, aiming at providing ideas and references to inspire research and technological advancements in this field.

Principles of dry chemical analysis

Dry chemical analysis uses dipsticks, also called reagent strips, as shown in **Figure 1A**, to determine the presence and concentration of the labeled substances. A urine dipstick is composed of multiple reagent pads attached to the plastic carrier foil. Each reagent pad typically contains a four-layer structure, a nylon mesh, a piece of reagent paper, a piece of absorbent paper, and a plastic carrier foil, as shown in **Figure 1B**. After dipping the dipstick into urine, the nylon mesh on the surface prevents biomolecules from entering the reagent paper and protects it from contamination, while the absorbent paper beneath the reagent paper absorbs excess urine, and blocks incident light transmission. The chemical reaction occurs in the reagent paper, resulting in a color change on the pad's surface corresponding to the substance that measured.

Figure 2 shows the color chart of an 11-pad dipstick, as well as qualitative and semi-quantitative descriptions of each item, with the lightest color on the left side and the darkest color on the right side. Generally, to each item, the deeper the color of an item, the higher the concentration, whereas the lighter the color, the lower the concentration.

Thus, the qualitative and semi-quantitative descriptions of each item can be determined based on color recognition. The following are methods that are used to recognize the color of each item.

Color recognition methods

Urinalysis based on viewing with naked eyes

Some color differences can be distinguished by viewing with naked eyes. When it comes to the recognition of color, human eyes can distinguish around 100 shades of grey values and approximately 7 million different colors. However, eyes - the human vision system - are often not as accurate as digital machine vision. Moreover, as for urinalysis based on viewing with eyes, the results may vary from person to person, causing recognition errors. Besides, checking over ten parameters in each test makes it extra challenging. **Figure 3A** shows that the reagent pads are being compared to the color chart sticked on the canister.

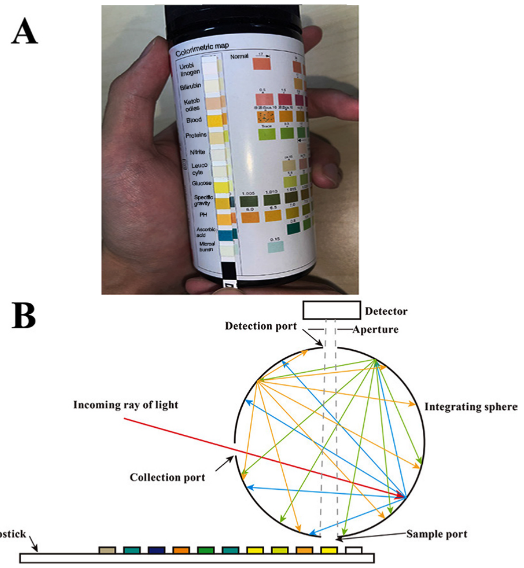

Figure 3. Conventional urinalysis with color detection methods. (A) Urinalysis based on naked eyes; (B) Urinalysis based on the integrating sphere.

Urinalysis based on an integrating sphere

An integrating sphere is a highly reflective device that is placed above the pad of the dipstick so that the incoming ray of light enters the sphere, bounces around the highly reflective diffuse surface of the sphere wall, and finally impinges upon the detector, which is also a part of the integrating sphere assembly. The name, integrating sphere, derives from one of the primary functions of the device, namely that it spatially integrates the light flux, in our case, the light reflected from the pad of the dipstick.

As is shown in **Figure 3B**, when there is no pad placed under the sample port, the amount of light obtained by the detector is relatively large. However, when there is a reagent tape placed under the sample port, the amount of light obtained by the detector drops, which is proportional to the color depth of the measured pad, that is, inversely proportional to the concentration of the substance contained in the pad.

Urinalysis based on color sensors

A color sensor is a device that can measure the RGB color (red, green and blue) values of the object being assessed [7-9]. It has two measurement modes, the first of which involves determining the proportion of red, green, and blue light. Changes in light intensity are the only variables that have an impact on this measurement method, and changes in detecting distance have no impact. The second mode utilizes the intensity of reflected red, green, and blue light to detect target substances, although the sensor's position may have an impact on the outcome [10]. This is generally tested by using a white light source to illuminate the urine reagent pad and using a color sensor to receive the reflected light to obtain the color value of the corresponding substance in the test pad. The exact working principle is shown in **Figure 4**. The color sensor is particularly suitable for tasks that require color recognition. Numerous researchers have developed color sensor-based urine test strips for applications involving color recognition [11-15].

Urinalysis based on image sensors

Image sensors have become a crucial component of cell phones, as much as they are in professional cameras, observatories, and space telescopes. According to the design of the sensor's pixel layout, image sensors can be classified into surface array sensors or line array sensors. The surface array sensor is made up of a two-dimensional sensor element that can capture an entire two-dimensional image at once, but the image quality can be easily influenced by the amount of light present, the angle from which it is being taken, and other variables. It is also susceptible to geometric distortion [16]. Using a power unit to drive the line array image sensor or target object to generate a two-dimensional image by scanning line by line, this method produces images with high resolution and no geometric distortion. Line array sensors are made up of an array of one-dimensional photoreceptors [17].

Figure 5 shows the principle of urinalysis based on image sensors. Linear light sources, generally composed of three LED lights, irradiate the reagent pad, and the reflected light is captured by the charge-coupled device image sensors, which produce an image depicting the color distribution of the tested reagent pad.

There are numerous studies that use image sensors for urine composition analysis. They primarily use smartphone cameras as a medium for color recognition of urine dry chemical reagent bands [18-23]. Again, relying on the benefits of smartphones, some researchers have developed supporting artificial intelligence techniques to replace human judgment, enabling prompt generation of test results [24-26]. However, due to the limitations of smartphones and development platforms, most of these studies still rely on image sensors for urine composition analysis [27, 28].

Discussion

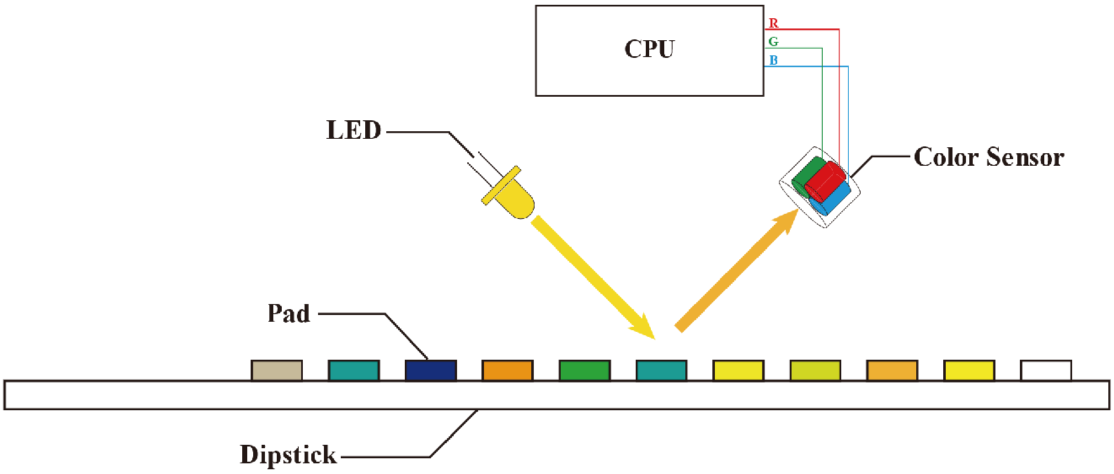

Figure 4. Working principle of color sensor-based dry chemical analysis. The white light emitted from the LED hits the reaction pad and the resulting reflected light is picked up by the color sensor. The color filter in the color sensor identifies the light intensity of the three colors, which is then processed by the CPU to obtain the color of the reaction pad.

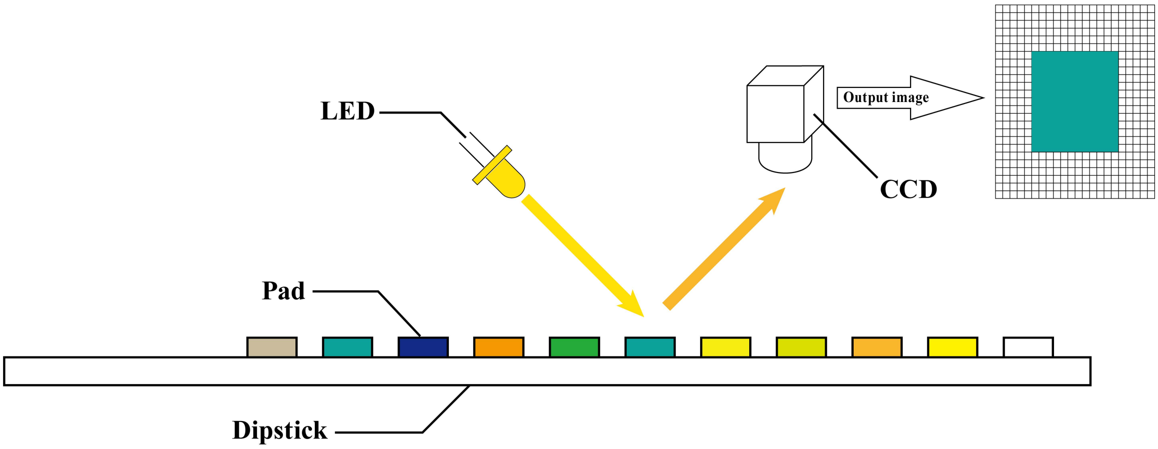

Figure 5. Urinalysis based on image sensors. CCD, charge-coupled device.

Urinalysis is the examination of a urine sample for the diagnosis of urinary tract disorders as well as a variety of metabolic, systemic, and endocrine disorders. This test is usually performed by means of a dipstick loaded with several square pads containing regents that correspond to different objective compositions to be tested.

In section 3, four methods for color recognition of the reagent dipstick after immersion in urine are presented.

Regarding urinalysis based on viewing with eyes, the sensitivity of the human eyes to variations in color brightness and chromaticity can vary. Different individuals may have distinct responses to the same reagent pad due to both subjective and objective factors. Therefore, this method is only used in situations when the use of instruments is inconvenient or only at home. But some people with color weakness or color blindness may produce inaccurate results [29].

Currently, urinalysis based on an integrating sphere is widely used in clinical settings. However, this method requires an ideal integrating sphere, wherein: (1) the inner surface of the integrating sphere is a complete geometric sphere with equal radii everywhere; (2) the inner wall of the sphere is a neutral and uniformly diffusing surface that maintains consistent diffuse reflectance for incident light across various wavelengths; (3) there is no object in the sphere, and the light source should be regarded as an abstract light source that only emits light and has no entity. Therefore, this method has a high requirement for optical equipment.

Urinalysis based on a color sensor can recognize subtle color differences with a high degree of sensitivity, offering a user-friendly and straightforward operation that doesn't necessitate specialized expertise. However, it requires white balance processing and calibration. In order to further improve its performance, color sensor recognition technology based on optical fiber transmission has been studied recently [14].

In the context of urinalysis utilizing image sensors, it should be noted that both charge-coupled device (CCD) sensors (discussed in this paper) and complementary metal-oxide-semiconductor (CMOS) sensors (not covered in this paper) primarily measure the intensity of light at individual pixels. When adopted, illumination correction is needed, considering different light source environments in image acquisition module of charge-coupled device, as this can lead to deviations in the color image of the tested reagent pad. Since both urine and reagent pads possess colors, color calibration is also essential.

Conclusion

In this paper, we summarize four urine dry chemical analysis methods, including urinalysis based on human eyes, integrating sphere, color sensors, and image sensors. Urinalysis based on an integrating sphere is widely employed in clinical settings. However, with the progress of science and technology, urinalysis based on color sensors and image sensors will become increasingly popular due to their lower costs, higher accuracy, and easier maintenance, especially for home settings.

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