The Quest for Hydration Management

Simplifying the Complexities of Measuring and Reporting Hydration

Rockley® Photonics
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Abstract
Maintaining an appropriate level of hydration is essential for a healthy life. The virtues of hydration are so widely recognized today that they are frequently touted by celebrities, clinicians, friends, teachers, experts, and colleagues. Staying properly hydrated is one of the best habits that most people can adopt for their overall health and wellness. Hydration status can have a significant impact in several areas, including a person’s mood, physical and mental performance, kidney function, and skin condition. However, managing hydration presents an interesting conundrum: it is easy to say, “Stay hydrated,” but maintaining healthy hydration habits can be quite challenging.

The human body is comprised of 50-60% water. The balance between water and key solutes (such as electrolytes, proteins, and glucose) is important for cellular function, and having the proper balance can ward off chronic disease and other illnesses. As people consume meals and drink beverages, the body’s mechanisms try to maintain a balance naturally, but the balance is delicate, and imbalances can occur abruptly as conditions change. Most people are unaware of how close their bodies may be to experiencing a problem arising from mild dehydration.

Understanding body hydration — and when it might not be balanced properly — could be extremely valuable for managing personal health and well-being. While there are several techniques in use today for assessing hydration levels, such as measuring body weight loss or analyzing urine, each of these methods has limitations and provides only an incomplete picture. The scientific consensus is that a combination of multiple techniques provides a more accurate assessment of body hydration than any one single technique. However, existing methods are generally not feasible for measuring hydration during a person’s normal routine — whether sleeping during the night, exercising at the gym, or simply going about one’s day.
To fill this need for a monitoring solution that assesses hydration levels and doesn’t impinge on a person’s lifestyle, Rockley Photonics has developed a silicon-photonics-based technique that could monitor hydration levels on a more routine basis. As part of Rockley’s non-invasive biosensing platform, the biomarker sensor is responsive to water concentration changes in the human body. Using this technology, Rockley has developed a novel hydration assessment technique that has the potential to better understand human hydration in an unprecedented way through a new measurement methodology.

To this end, Rockley has created a hydration index that simplifies the reporting of hydration levels, potentially helping everyone better understand their hydration status and delivering insights or recommendations tailored to each person’s individual hydration needs.

By providing the means to measure hydration levels non-invasively and continuously and by delivering information about hydration status through a novel, simplified index, the Rockley biomarker sensing platform has the potential to help people make smarter, more-informed decisions about managing their hydration.
Hydration as a Trend

The Concept of Hydration

The conventional wisdom is that the simple act of drinking water is healthy, and it has become an accepted norm across society to always have ready access to water. From the gym to the meeting room, one can see water nearly everywhere — whether in disposable plastic containers, in sleek hydro-bottles, in ruggedized canisters, in converted cross-purpose vessels, or in environmentally friendly pitchers and glasses. Staying hydrated has become a cardinal rule for promoting youth, wellness, beauty, and more.

When exactly did drinking water become so “cool?” (Pun intended.) The focus on staying hydrated has its roots in the 1970s, when people started wanting to stay fit, and exercise became a mainstream fad. Road running and “going to the gym” became increasingly common among the general population.

To capitalize on this trend, companies sponsored scientific research to explore the area of hydration. Starting with a focus on how hydration affects athletes, studies investigated dehydration under strenuous conditions. The results were very compelling. Research showed that even a little dehydration — 2% loss of body weight — can have a substantial impact on performance.

Perhaps more significantly, these studies made the important observation that even a slightly dehydrated state may not trigger a sense of thirst. To maintain optimal performance, a person must learn to drink water even when not thirsty and thereby train the body to tolerate extra fluid — i.e., pre-hydrate or hyperhydrate. Drinking water
or a drink rich in electrolytes is often an effective solution for keeping the body in optimal condition.¹,²

As people in the United States embraced exercise and aerobic fitness, the bottled water industry saw an opportunity to expand into the yet-untapped consumer space. Prior to this shift, bottled water had been sold primarily to restaurants as beverages to be served with meals. One company led this charge into the consumer market: Perrier.

**Case Study: Convincing Consumers to Pay for Water³**

For generations, water had been a free or nearly free resource that was safely delivered to millions of homes and was readily available from a kitchen tap. Then, in the 1970s, despite the widespread availability of clean drinking water, Perrier had a different idea: selling bottled fizzy water in green glass bottles shaped like bowling pins. The company launched a nation-wide U.S. campaign to convince young, well-to-do baby boomers to pay for sophisticated, classy water. Spending an estimated $2.5-5 million ($18-36 million in 2022, adjusted for inflation), Perrier created a series of straight-talking television ads. Narrated by the deep baritone voice of Orson Welles, these commercials promoted the message that Perrier was “more quenching, more refreshing, and a mixer par excellence… naturally sparkling, from the center of the earth.” To nurture a feeling of “exclusivity” and “status,” Perrier set the price of a bottle of its sparkling water just slightly on the high side — but not too far out of reach — further reinforcing Perrier’s image of excellence and promoting its reputation as a status symbol.

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³ [https://priceonomics.com/the-ad-campaign-that-convinced-americans-to-pay/](https://priceonomics.com/the-ad-campaign-that-convinced-americans-to-pay/)
Recognizing that its target audience had an obsession with running, Perrier also cultivated a “sporty” image by promoting itself as the drink of choice for fitness. The company sponsored the annual New York City marathon and financed over 200 parcours (fitness trails) throughout the United States. The company also developed longstanding relationships across the sporting industry, most notably its four-decade sponsorship with Roland-Garros,4 home of the French Open tennis grand slam (which it still sponsors today). Through these efforts, Perrier succeeded in becoming an alternative to sports drinks.

The launch of Perrier in the United States was hugely successful, with annual bottled water sales increasing from 2.5 million bottles in 1975 to over 75 million bottles in 1978. Perrier inspired other beverage companies to follow suit and thus began an era of “Big Water.” In subsequent decades, companies like Evian, Arrowhead, Poland Springs, Seagram’s and Schweppes, Coca Cola, Pepsi-Co, and more have all competed for the hearts of consumers with sparkling, flat, flavored, low-sugar, and many other variations of water and sports drinks.

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The Science of Hydration

Factors Affecting Hydration

Expanding from its market-driven origins in “commercial” research, the science of hydration has evolved considerably in recent years. Athletes and professional sports organizations have teamed up with academic research institutions to explore the fundamental physiology of the human body during exercise. Today, there are a growing number of practical guidelines that highlight personalized hydration strategies for optimizing performance and enhancing the safety of athletes while engaged in sporting activities. The current consensus recommends that good hydration practices include the following:

- Beginning exercise in a state of euhydration (optimal water balance)
- Preventing the onset of dehydration during exercise
- Replacing residual fluid losses during recovery prior to the next exercise activity

As the communication regarding hydration has evolved over the decades, there has been an abundance of information — and misinformation — about how to stay hydrated. While it is widely acknowledged that drinking water is good for you, how much you should drink is not nearly as straightforward. Understandably, most consumers are not professional athletes, and their bodies’ needs will vary accordingly. A person’s fluid needs are unique to each individual and rely on factors such as the rate of perspiration, exercise mode, exercise intensity, exercise duration, and environmental conditions.5

Drinking water is good for you, but how much you should drink is not nearly as straightforward. Each person’s fluid needs are unique.

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Impact of Hydration

The human body is very good at maintaining fluid balance. When water intake is low, the body will work hard to conserve every bit of water possible through the kidney to reduce urine. When water intake is high, the body will shed excess water, mainly through increased urine output. For each individual, the proper level of water intake depends on many factors, including age, sex, activity level, climate, environment, and more.

Older adults generally drink less water and are particularly prone to hydration challenges. Not only does the thirst sensation become more attenuated as the body ages, but kidney function also declines, and there are often decreases in cognitive function. The prevalence of chronic kidney disease (CKD) and heart failure are markedly higher among adults over the age of 65.6

There is also the inconvenience of nocturia among the elderly (waking during the night to urinate). These late-night trips can often become very costly, either directly to a person’s health (lack of sleep, increased risk of fall, etc.) or indirectly to a loss of

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productivity and decreased quality of life. Unfortunately, while the treatment for nocturia is relatively straightforward and often involves simply drinking less water in evening hours, this reduction in water intake can sometimes lead to dehydration issues.

Despite the benefits of staying hydrated, recent findings have shown that most people are not drinking enough water. Further exacerbating the situation, they often consume sugary beverages as well, which can diminish the beneficial effects of drinking plain water. For many years, it has been broadly understood that obesity in humans may be partly associated with low hydration. Serum osmolality (the concentration of solutes in the blood) is frequently higher in obese people. Consuming too little water and too much sugar and salt increases fat production, which amplifies the risk of obesity and metabolic dysfunctions, such as fatty liver disease, insulin resistance, diabetes, high blood pressure, and more.

Simply stated, drinking water is critical for health and longevity. Even if everyone understands this importance, however, maintaining a healthy fluid balance can be complex, because it depends on many factors that are unique to each individual. While there are countless efforts to simplify the advice regarding hydration and provide guidelines to establish concrete goals, there is no “one size fits all” approach. It can be challenging for individuals to sift through these myriad recommendations, interpret the advice, and adopt healthy hydration habits that fit into their daily lives.

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The “8x8” Debate

One of the most commonly shared recommendations is to drink eight glasses of water a day. Despite the widespread repetition of this recommendation, the objective proof for this guidance appears to be lacking. Older literature points to the U.S. Food and Nutrition Board’s guideline in 1945, which provides advice on the volume of fluids to drink per day:

“A suitable allowance of water for adults is 2.5 liters daily in most instances. An ordinary standard for diverse persons is 1 milliliter for each calorie of food. Most of this quantity is contained in prepared foods.”

While this document has been widely referenced since its publication, the last part of this passage has been generally overlooked. By selectively focusing attention on the first part of this guidance (perhaps because of its simplicity), the popular press, from The New York Times to health magazines, has propagated the recommendation that is now commonly expressed as “8x8” (eight glasses of eight ounces of water).

In 2002, Dr. Heinz Valtin, emeritus professor of endocrinology and renal physiology at the Geisel School of Medicine at Dartmouth University, examined the scientific significance of this advice and found there were no scientific studies that supported “8x8.” Instead, surveys of food and fluid intake on thousands of male and female adults, published in peer-reviewed journals, strongly suggest that such large amounts of water are not needed, noting that the individuals previously surveyed were presumably healthy and certainly not overtly ill.

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Despite the apparent lack of evidence, the simplicity of the “8x8” guideline, combined with the message that hydration is good for you, has become so strong that the practice and adherence to “8x8” have created the environment in which water bottles are now commonly viewed as a stylish accessory.

**Measuring Hydration**

Because casually taking a sip of water in just about any setting — during class, in a meeting, or on a video call — is now a social norm, the expectation is that we should collectively become a healthier, more hydrated society. However, multiple findings have shown the opposite: people are not drinking enough water. The National Health and Nutrition Examination Survey examined 4,000 children in the United States between the ages of 6 and 19 from 2009 to 2012. Using urine osmolality to determine whether participants were adequately hydrated, this study showed that more than half of children and adolescents are not adequately hydrated.10 (Urine osmolality and related laboratory tests will be discussed in more detail in “Combining Multiple Techniques” below.)

Chosen for its simplicity of implementation, this method of assessing hydration through urine osmolality provides a suitable snapshot of a single point in population trends. Developing a better understanding of hydration, however, would require more continuous monitoring over a longer period. Unfortunately, day-to-day, hour-to-hour hydration monitoring can be quite complicated, because water is stored and shifted between different sites throughout the body.

Other than fluid analysis, there are only a few indicators of hydration level that may be useful. The sensation of thirst is one, but it is slow, fairly unreliable, and relatively inexact. By the time a person feels thirsty, the body has already lost nearly 2 percent of its fluid compared to total body weight, resulting in mild dehydration. In other words, to maintain

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proper hydration, a person should drink water long before feeling thirsty. Other indicators of hydration status are urine color and output, where darker urine and lower output are often indicative of dehydration. Because these approaches do not provide adequate precision, clinicians often turn to other methods to assess fluid status, many of which have notable limitations.

Table 1 below summarizes the commercially available products for assessing hydration and highlights some of the advantages and shortcomings of each solution. Table 2 outlines several clinically accepted hydration assessment techniques performed in labs or point-of-care (POC) settings. Underscoring the methods outlined in both tables is the fact that even highly trained clinicians are limited by the access and/or techniques available to them.

<table>
<thead>
<tr>
<th>Solution / Method</th>
<th>Operating Principles</th>
<th>Advantages</th>
<th>Shortcomings</th>
</tr>
</thead>
</table>
| **Physical signs** (skin turgor, thirst, venous distension, sunken eyes, urine color/volume) | Visual examination or palpitation | • Familiarity (e.g., low urine volume + dark yellow urine = likely dehydration)  
• Quick field check  
• No instruments required  
• Free | • Some signs appear only after moderate dehydration is reached.  
• Some signs are unfamiliar to the average person. |
| **Lab / POC tests** | Serum/plasma or urine analysis; Other analyses (such as ultrasound) | • High validity  
• Trustworthy  
• Cleared by CLIA, FDA, AMA, etc. | • Clinical use only  
• Expensive  
• Instruments and trained personnel required  
• Best results with combined analyses  
• Confounding factors |
| **Wearable or other sensors** | Blood or skin water content analysis using optical sensors; Bioimpedence; Sweat analysis | • Convenient options: single-use through continuous monitoring  
• Ease of use  
• Low cost  
• Identification of baseline trends and deviation | • Less trust in reliability  
• Less clinical accuracy  
• Limited to fluid type analyzed  
• Confounding factors |

Table 1: Current Market Solutions for Assessing Hydration
### Table 2: Selected Characteristics of 13 Hydration Assessment Methods

<table>
<thead>
<tr>
<th>Hydration Assessment Technique</th>
<th>Body Fluids Involved</th>
<th>Cost of Analysis</th>
<th>Time Required</th>
<th>Technical Expertise Required</th>
<th>Portability</th>
<th>Likelihood of Adverse Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable isotope dilution</td>
<td>all (extracellular fluid and intracellular fluid)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2 or 3&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Neutron activation analysis</td>
<td>all</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Bioelectrical impedance spectroscopy</td>
<td>uncertain</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Body mass change&lt;sup&gt;b&lt;/sup&gt;</td>
<td>all</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Plasma osmolality&lt;sup&gt;c&lt;/sup&gt;</td>
<td>extracellular fluid</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>% plasma volume change</td>
<td>blood</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Urine osmolality</td>
<td>excreted urine</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Urine specific gravity</td>
<td>excreted urine</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Urine conductivity</td>
<td>excreted urine</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1</td>
</tr>
<tr>
<td>Urine color</td>
<td>excreted urine</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>24-hour urine volume</td>
<td>excreted urine</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Salivary flow rate, osmolality, total protein</td>
<td>whole, mixed saliva</td>
<td>2-3</td>
<td>2</td>
<td>3</td>
<td>2-3</td>
<td>1</td>
</tr>
<tr>
<td>Rating of thirst</td>
<td>Hypothalamus</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Key to ratings:

- 1 = small, little
- 2 = moderate
- 3 = great, much

- 1 = portable
- 2 = moderate
- 3 = not portable

<sup>a</sup> Depending on the type of isotope involved (i.e., radioactive, stable, non-radioactive)

<sup>b</sup> Using a floor scale

<sup>c</sup> Freezing point depression method

<sup>d</sup> Portable, hand-held meters are available

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Overcoming Key Limitations

Drawbacks of Current Approaches
The breakneck speed of scientific and technological advances across seemingly every industry has created the expectation among both consumers and clinicians that advances in health tracking and diagnostics will keep a similarly rapid pace. Faced with these expectations, device and component manufacturers have understandably accelerated their efforts to satisfy the need for quality products that provide insights into an expanding range of health conditions, including body hydration. However, the efforts regarding hydration face a fundamental challenge: dehydration and hyperhydration are difficult to diagnose. Fortunately, as research in this area continues, understanding what is working in realm of hydration assessment — and what isn’t — can lead to meaningful, high-impact changes in health, wellness, and medicine.

There is no single “gold standard” method for measuring hydration, simply because there is no universal, easy-to-use, and easy-to-understand scale for quantifying an individual’s hydration status. With a multitude of factors affecting hydration, the model surrounding physiological hydration can be exceptionally complex. Fluid imbalances, which can lead to serious physical complications, may appear in a variety of scenarios.

Current medical and scientific consensus states that a combination of techniques and tests significantly improves adequate prediction of conditions like dehydration. One of the most widely used reference methods for assessing dehydration in both clinical practice and research is body weight loss. In many lower-risk scenarios, it can be assumed that a decrease in weight can be attributed to loss of water and electrolytes through primarily sweat and urination. Based on this assumption, for example, recreational long-distance runners may measure their body weight to try and gauge how much fluid they need for adequate rehydration.
However, this method of assessment can be inaccurate and has its limitations. In most cases, a loss in body mass underrepresents a person’s true dehydration status. The primary constraint is that starting weights are rarely tracked beforehand, and there are factors other than changes in fluid status that can affect body weight. To continue our example, the recreational long-distance runners may have fueled up with a meal beforehand or eaten food along the way, making it more difficult to accurately assess how much fluid they lost during the run.

In higher-risk scenarios, such as gastroenteritis presenting with acute vomiting and diarrhea, the patient must be stabilized before a more reliable weight measurement can be taken. This stabilization period may take hours or even days. In these cases, catabolism and nutritional losses could further contribute to the underestimation of dehydration.

**Combining Multiple Techniques**

As the medical community explores new methods, the prevailing view is that combining the measurement of weight loss with additional tests could significantly improve the accuracy of assessing hydration. When a patient presents to a clinic with symptoms indicating either dehydration or hyperhydration, standard practice is to run blood and urinary evaluations. Even though these laboratory tests are time-consuming and often costly, they provide a validated assessment of the osmolality and electrolyte concentrations in physiological fluids.

Despite the accuracy of the results, each laboratory test has its limitations, and one single lab test cannot possibly account for the multitude of dynamic properties affecting fluid balance. To bring a sense of order to the chaos, recent scientific consensus has narrowed its focus to a few key indicators deemed to be the most reliable in correctly
representing a person’s hydration status. Here is a quick overview of three of the most commonly used reference tests:

- **Urine Osmolality** measures the concentration of dissolved particles in urine and informs practitioners about how well the kidneys can maintain fluid homeostasis and water balance. The concentration capability of healthy kidneys is between 50 and 1,200 mOsm/kg water. Restricting fluid intake for approximately 12 hours (for example, from dinner to breakfast) typically results in a urine osmolality of 850 mOsm/kg or greater. In a healthy person with good kidney function, urine osmolality is 3-4 times serum osmolality.

  High urine osmolality may indicate one or more conditions: dehydration, excess protein from dietary consumption, excess sugar (glycosuria) or sodium (hyponatremia), or conditions of the heart, liver, or adrenal glands. Low urine osmolality may be indicative of hyperhydration or water toxicity, the use of diuretics, or conditions like diabetes insipidus, and kidney disease.

  **Limitations:** Drinking a large bolus of water at once, or a high total volume of water throughout the day, may result in low urine osmolality. Consuming excess protein may also raise osmolality.

- **Urine Specific Gravity** compares the density of urine to the density of water. Similar to urine osmolality, it is a way to measure the concentration of solutes in urine. The physiologic range is 1.001-1.040. High and low specific gravity can be affected by conditions similar to those that impact urine osmolality, respectively.

  **Limitations:** The utility of urine specific gravity is limited by weight and number of solutes. For example, the presence of large molecules in the urine, such as glucose, will correlate to a falsely high specific gravity.

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• **Serum Osmolality** measures the concentration of dissolved substances in the blood, including sodium, potassium, chloride, glucose, and urea. A serum osmolality of 301 ± 5 equivalates to a 4.5% loss of body mass in healthy males.\(^{13}\) Factors that increase serum osmolality include free water loss, diabetes insipidus, sodium overload, and hyperglycemia. Factors that decrease serum osmolality include isotonic fluid loss, syndrome of inappropriate antidiuretic hormone secretion (SIADH), diuretics, adrenal insufficiency, and kidney failure.

*Limitations:* Serum osmolality is often used as a “standard” for measuring dehydration, though it is well understood that values do not fluctuate widely during acute and mild episodes, and blood solute concentration is tightly regulated.\(^{14}\) Also, serum osmolality is not a direct measure of cellular hydration and often returns to its set point while fluid shifts to other compartments.

The following table (Table 3) outlines the generally accepted ranges of these important reference tests. It is important to note that clinical guidelines may differ slightly. For example, many sports medicine professionals may use adjusted clinical laboratory thresholds for hydration monitoring in athletes.

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Table 3: Accepted Ranges of Hydration Reference Tests

<table>
<thead>
<tr>
<th></th>
<th>Urine Osmolality (mOsm/kg)</th>
<th>Urine Specific Gravity</th>
<th>Serum Osmolality (mOsm/kg)</th>
<th>Weight Loss (% of Body Mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhydration</td>
<td>&lt;80 to &lt;500</td>
<td>1.001 to &lt;1.005</td>
<td>&lt;265 to &lt;285</td>
<td>weight gain</td>
</tr>
<tr>
<td>Normal Hydration</td>
<td>500 to 700</td>
<td>1.005 to &lt;1.020</td>
<td>285 to &lt;295</td>
<td>0% to &lt;2%</td>
</tr>
<tr>
<td>Mild Dehydration</td>
<td></td>
<td>1.020 to 1.040</td>
<td>295 to &gt;320</td>
<td>2% to &lt;6%</td>
</tr>
<tr>
<td>Moderate Dehydration</td>
<td>700 to 1200</td>
<td>1.020 to 1.040</td>
<td>295 to &gt;320</td>
<td>6% to &lt;10%</td>
</tr>
<tr>
<td>Severe Dehydration</td>
<td></td>
<td></td>
<td></td>
<td>≥10%</td>
</tr>
</tbody>
</table>

- The American College of Sports Medicine (ACSM) position stance states that 700 mOsm/kg is considered to be indicative of dehydration, though other guidelines utilize a higher threshold (800-850 mOsm/kg water).
- The National Collegiate Athletic Association (NCAA) targets a urine specific gravity of ≤1.020 to monitor hydration in athletes. The National Athletic Trainers’ Association (NATA) target is lower, at 1.010.

The list of hydration indices presented here is not exhaustive. Each scenario will have its own circumstances and may require additional tests to gain a more accurate assessment of a person’s hydration level, such as serum sodium, chloride, glucose, and blood urea nitrogen (BUN). Perhaps the most important takeaway is that the combined use of these tests is stronger than each individual test on its own.
A Novel Hydration Assessment Technique

Filling the Gap
As noted above, even though a combination of techniques can be used to provide an assessment of body hydration that may be more accurate than any one single technique, it is simply not feasible or convenient for people to measure their body weight or have their urine analyzed on a continuous basis. A simpler, less cumbersome, and more accessible method is needed.

Leveraging its expertise in silicon photonics, Rockley has developed a photonics-based sensing solution that could monitor body hydration levels on a more routine basis. By combining the measurement of four key hydration metrics, the Rockley biomarker sensing platform provides a monitoring solution that assesses hydration levels with a high degree of confidence — and doesn’t impinge on a person’s lifestyle.

Using Photonics to Sense Hydration
The Rockley biomarker sensing platform features a non-invasive, photonics-based sensor that can monitor water absorption on a continuous basis and is sensitive to concentration changes of water within the interstitial space. The Rockley sensor generates multiple laser wavelengths that penetrate the skin at varying depths to target water spectra features specific to water. The sensor applies the principle that changes in the concentration of components within the skin (collagen, lipids, and water) can be observed by monitoring water absorption. As water in the dermis diminishes, the concentration of solutes become higher, thereby changing the degree of water absorption.

Using silicon-photonics-based lasers, Rockley’s biosensing platform could enable a new and improved solution for measuring hydration.
By analyzing changes in water absorption, a Rockley-powered wearable device could estimate a person’s total body hydration status in real time. Having continuous access to hydration levels would not only provide more timely information but could also help avoid the high cost of laboratory assessments.

**Validating the Model**

In preliminary IRB-approved\textsuperscript{15} human studies, Rockley researchers examined hydration levels before, during, and after exercise. Twenty-three study participants were asked to perform moderate-intensity exercise by riding on a stationary bicycle for ninety minutes. These studies have confirmed that the overwhelming majority of water loss occurs through perspiration. The body’s sweat mechanism is the primary source of heat dissipation during physical activity, accounting for approximately 80% of total heat lost.

\textsuperscript{15} Approved by WIRB – Copernicus Group Institutional Review Board.
To develop a complete picture of the physiological response to the protocol, it was important to construct the parameters. A vast number of reference measurements were collected, at the beginning to establish a baseline and at frequent intervals throughout the entire length of the protocol. Body mass, urine osmolality, urine specific gravity, and serum osmolality were a few of the key metrics.

Figure 3 below shows the urine and blood parameters collected throughout the exercise-induced protocol. Each sampling period was spaced at 30-minute intervals. This protocol produced the expected measurement results, properly identifying the various states of hydration, as outlined in Table 3 above.
More notably, our studies have revealed a promising application for the Rockley sensor: the potential to classify levels of hydration status and anticipate hydration changes before they may become an issue. By comparing the subjects’ hydration status before activity (when fluid intake was controlled) to their hydration status after activity but before rehydration, the Rockley model was able to successfully predict dehydration with high probability in nearly all cases. The same model may be applied in scenarios involving passive dehydration.

The performance of Rockley’s model is reflected in the sensitivity and specificity of the measurements produced by the Rockley biosensing platform.

- **Sensitivity** refers to the ability of a test or model to predict a positive outcome: the better the sensitivity, the lower the risk of the model delivering a false negative. Based on the test results of our studies, the sensitivity of our hydration model to predict dehydration was 0.99 — i.e., our model correctly predicted dehydration 99% of the time.
• **Specificity** is equally important and refers to the ability of a test or model to measure a negative outcome: the higher the specificity, the lower the risk of delivering a false positive. Based on the test results of our studies, the specificity of our hydration model was 0.82, meaning our model correctly predicted that a subject was euhydrated (or not dehydrated) 82% of the time.

The following figure (Figure 4) illustrates these results. The Rockley model was able to successfully predict dehydration and euhydration in subjects with 99% sensitivity and 82% specificity.

![Figure 4: Prediction of Hydration Status by Rockley Model](image)

The studies also measured the utility of the Rockley sensor in monitoring the fluid balance during active rehydration through changes in dermal water volume and other spectrally derived data points, delivering actionable information about when hydration levels have returned to an optimal state.

The initial results of Rockley’s hydration studies have been encouraging, and ongoing studies should allow Rockley to expand the protocol and explore a wider application of use cases. The findings of these studies could allow Rockley to refine the model’s predictive capabilities and develop a new tool for assessing hydration.
**Introducing the Rockley Hydration Index™**

To simplify the complex process of measuring body hydration, Rockley has created a novel hydration index for reporting relative and individualized hydration levels. The index is founded on clinically recognized laboratory and field-appropriate hydration assessment techniques, plus other relevant physiological parameters, correlating the values with spectral data generated by the Rockley infrared (IR) sensor. It is built upon the idea that the sum of hydration measurement techniques is more effective and more valuable than individual measurements. The Rockley Hydration Index will boil all the complexities of hydration measurement down to a simple, color-coded, numerical indicator, making it easy for people to check if they are over- or under-hydrated with a single glance.

*Figure 5: Rockley Hydration Index*

With the ability to continuously monitor changes in body water levels, the Rockley biosensing platform has the potential to provide actionable feedback and help people make better-informed choices about their personal hydration needs, including the amount and timing of fluid consumption.
The Power of Actionable Insights

**Encouraging Healthy Hydration Habits**

Tracking water consumption and maintaining healthy water drinking habits are not always easy tasks in the often-hectic lifestyles that people live today. If empowered with the ability to monitor hydration on a real-time basis, smart watches and other wearable devices could provide actionable information that helps people improve their hydration habits — potentially making these devices as important to managing hydration as those ubiquitous bottles of water.

To enhance the quality of insights into hydration, leading manufacturers have started to explore the integration of biomarker sensors tracking hydration levels to complement the manual entry of water consumption. These forward-looking companies understand that drinking water and healthy behaviors are driven by habits – and that providing contextual cues could potentially trigger “automatic” responses and help people make positive changes in their behavior. Consumers are notorious for making excuses and succumbing to all kinds of barriers: not remembering, ignoring thirst cues, lacking motivation to carry a bottle, and more. The effort to encourage healthier water habits would be assisted by having a reliable, user-friendly, automated technique for hydration assessment.

**One of Many Critical Biomarkers**

As a solitary biomarker, assessing hydration can provide important insights about certain health conditions, simply based on understanding whether the person is hydrated or dehydrated. However, because this is just one biomarker, understanding a person’s overall health may be limited. Developing a more complete picture would require combining this hydration assessment with an understanding of other key biomarkers.
The Rockley platform intends to provide non-invasive, real-time monitoring of a broad range of multiple biomarkers, including hydration, core body temperature, blood pressure, heart rate, blood oxygen, lactate, ethanol, urea, glucose, and more. The platform will aggregate the data from all these biomarker measurements and analyze them holistically, leveraging Rockley’s cloud-based analytics and AI capabilities. This enhanced level of analysis has the potential to deliver valuable insights about individual health — and perhaps eventually help enable early disease detection or predict health-related outcomes.

As the platform incorporates increasingly larger data sets from multiple measurements and across several domains (number of subjects, population samples, time frames, time duration, clinical annotations, etc.), recent advances in machine learning and AI will potentially allow the platform to develop a deeper understanding of the relationship between spectral data and individual biomarkers. In turn, these new insights should help the Rockley sensing platform improve the ability to monitor health conditions, enhance the interpretation of key indicators, and support new use cases and applications.

A reliable, user-friendly, automated technique for hydration assessment would be a valuable tool for encouraging healthy hydration habits.
Summary
Samuel Taylor Coleridge once wrote, “Water, water everywhere, nor any drop to drink.” This paradox of “close but not quite right” could easily apply to the current state of hydration measurement. There are numerous techniques for assessing hydration levels, and many of them can be quite useful in certain circumstances. However, they typically are not equipped to handle the many complexities affecting body hydration and may not provide an easy way for people to manage their individual hydration needs in an appropriate manner.

By enabling the continuous and non-invasive measurement of hydration, the Rockley biomarker sensing platform has the potential to provide real-time recommendations for managing personal hydration. These recommendations will not rely on a “one size fits all” maxim but will instead focus on the specific needs of each individual. Rockley takes hydration measurement one step further by introducing a novel hydration index that provides a simple method for people to understand their hydration level.

By monitoring hydration in real time and simplifying how hydration levels are reported, Rockley’s unique sensing platform has the potential to provide key insights about individual water usage and consumption and help people make better-informed decisions about their hydration, health, and well-being.
About Rockley Photonics

A global leader in photonics-based health monitoring and communications solutions, Rockley Photonics is developing a comprehensive range of photonic integrated circuits and associated modules, sensors, and full-stack solutions. From next-generation sensing platforms specifically designed for mobile health monitoring and machine vision to high-speed, high-volume solutions for data communications, Rockley is laying the foundation for a new generation of applications across multiple industries. Rockley believes that photonics will eventually become as pervasive as micro-electronics, and it has developed a platform with the power and flexibility needed to address both mass markets and a wide variety of vertical applications.

Formed in 2013, Rockley is uniquely positioned to support hyper-scale manufacturing and address a multitude of high-volume markets. Rockley has partnered with numerous tier-1 customers across a diverse range of industries to deliver the complex optical systems required to bring transformational products to market.