The Turnover of Body Water as an Indicator of Health

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Abstract Water homeostasis is essential for healthy living. Body water turnover, meaning the replacement of body water that is lost in a given period of time, has been examined in a number of previous studies, and a review of their results has yielded the following findings. Children up to 15 years of age show higher body water turnover than adults, although it is not clear how the aging process influences body water. Among people of similar age, the rate of body water turnover seems to be higher in those who exercise than in those who are sedentary. Therefore we hypothesized that healthy individuals have a higher body water turnover than unhealthy individuals whose metabolic balance, as indicated by water turnover, has broken down, and that a prolonged condition of excessively slow body water turnover may be associated with a lower level of metabolism. If so, body water turnover can be an indicator of human health. However, there is a paucity of information regarding water turnover rates in individuals with various physical characteristics. This study indicates the need for further investigation of body water turnover levels associated with significant changes in physiological condition and metabolic state.

Keywords: body water turnover, water homeostasis, hydrometry, D₂O, indicator of health

Introduction

It is well known that water is the most significant component of the body. All chemical reactions that are essential for maintaining human life take place in the body's water. Water provides transportation and delivery of the body's different tissues, regulates body temperature, and maintains blood pressure for proper cardiovascular function. We would die much more quickly if deprived of water than we would if deprived of any other substance. Abnormalities in the volume and composition of body water are important clinical problems and are of concern for almost all seriously ill hospitalized patients. Understanding and treating these disorders require knowledge of fluid shifts between intracellular and extracellular compartments before and after therapy. For instance, edema, one of the abnormalities in the volume of body water, refers to the presence of excess fluid in the body tissues. Edema develops through abnormalities in the capillary fluid exchange mechanism, which is caused by high capillary pressure, low concentration of plasma protein, increased permeability of the capillary pores, and blockage of the lymphatic system. Abnormalities in the volume of body water can occur in the human body even in a healthy state. If water loss exceeds fluid intake and metabolic water production, dehydration will occur. Dehydration denotes the dynamic loss of body water, or the transition from euhydration to hypohydration. Dehydration-mediated heat injuries can be life-threatening for healthy exercisers.

Water homeostasis is a very important clinical consideration for healthy living. In the past, body water turnover, which shows water homeostasis in the human body, has been examined in several studies. These results are summarized as follows: 1) Children up to 15 years of age showed a higher body water turnover than adults do, although it is not clear how the aging process influences body water turnover because of a lack of data on body water turnover in elderly people. 2) Among same-aged people, the body water turnover rate seemed to be higher in the exercise group than in the sedentary group. 3) Environmental differences may affect body water turnover.

Most of these studies were limited to specific groups of people and/or special environments, and only a few studies have been conducted so far into the relationship between human health status and body water turnover in people in general, especially elderly people.

This article will address the biological and physiological significance of water, and review previous research on body water turnover in humans. Furthermore, we will discuss whether body water turnover reflects human health status, and will propose that body water turnover is a significant indicator of health.
Biological and Physiological Significance of Water

Human body water plays an important role in human life. Water is the most abundant substance in the human body, constituting about 60% of body mass in a reference man, or 50% in a reference woman (Wilmore and Costill, 1994), although this percentage can change, depending on sex, age, and percentage of body fat. As a person grows older and develops a greater percentage of body fat, the percentage of total body water (TBW) gradually decreases.

As shown in Fig. 1, the TBW is distributed among two major components: intracellular fluid (ICF) and extracellular fluid (ECF). ICF constitutes about 40% of the total body mass in healthy individuals.

All chemical reactions take place in ICF (Guyton and Hall, 1996). Each of the 100 trillion or more cells in a human body is a living structure that can survive indefinitely and, in most instances, even reproduce itself provided its surrounding fluids contain the appropriate nutrients. The principle fluid medium of the cell is water, which is present in most cells other than fat cells in a concentration of between 70% and 85%. Many cellular chemicals are dissolved in the water, while some are in particulate form or enclosed by membranes. Chemical reactions take place among the dissolved chemicals or at the surface boundaries between the suspended particles or membranes and the surrounding water.

The ECF is the sum of interstitial fluid volume, which is the total fluid in the spaces between the cells, and the blood plasma volume. ECF accounts for about 20% of body mass. The two largest components of the ECF are interstitial fluid, which makes up about three-fourths of the ECF.

The ECF is continually mixed and transported by the blood throughout the body, transporting nutrients to the cells and excreta away from the cells (Guyton and Hall, 1996). During physical activity, water plays several critical roles in human body. As described by Wilmore and Costill (1994), for instance, blood plasma, which is a kind of ECF, is primarily water. Red blood cells, which act via the blood plasma, carry oxygen to active muscles. Blood plasma transports nutrients such as glucose, fatty acids, and amino acids to muscles, and transports hormones that regulate metabolism and muscular activity to target tissues during exercise. Carbon dioxide and other metabolic wastes leave the cells and then enter the blood plasma to be cleared from the body. Body fluids contain buffering agents to maintain proper pH when lactate is being formed. Blood plasma volume is a major determinant of blood pressure, and thus of cardiovascular function. Water facilitates the dissipation of body heat that is generated during exercise.

In a healthy state, the body’s water content is often neglected because the volume of body water is well regulated and water has no caloric value. However, during exercise, a loss of 3% of body mass, induced mainly by sweating, can significantly limit human performance (Guyton, 1984). Furthermore, a water loss of 9 to 12% from the human body can lead to death (Wilmore and Costill, 1994). Thus, water is the most significant component of the body, and it is essential to physical activity.

The Term “Body Water Turnover”

Body water turnover means the replacement of body water in a day or other given period, and shows body water homeostasis. Body water homeostasis, expressed as fluid balance, is a very important clinical consideration. Body fluid balance consists of a comparison of the total fluid intake with the total fluid output over a 24-h period. Human body water balance per day is shown in Table 1. It is believed that a highly variable fluid intake must be carefully matched by equal output from the body to prevent body fluid volumes from increasing or decreasing. However, several variables affecting fluid gain depend on levels of physical activity. For instance, metabolic water production varies depending on the rate of energy expenditure: higher metabolic rates produce more water. The volume of sweat is normally only about 100 ml/day, but water loss in sweat occasionally increases to 1 liter/hour in very hot weather or during heavy exercise. Although these values indicate that water turnover is influenced by physical activity level, little attention has been given to the relationship between health status and body water turnover.

To measure body water turnover, the disappearance of tracers, such as deuterium (D2O) and tritium, has been studied by taking samples during several days after oral or intravenous administration. Water turnover has been described in several studies since Schlorb et al. (1950)
reported on the dynamics of D$_2$O for measurement of TBW. However, there is a paucity of information regarding water turnover rates in people with various physical characteristics. It is for this reason that, although hydrometry techniques implicitly estimate body water turnover when used to measure TBW, investigators do not publish the water turnover values.

**Previous Research on Body Water Turnover**

Schlorb et al. (1950) studied the disappearance of D$_2$O by taking samples up to 40 days after intravenous administration, and they recognized that the daily disappearance of D$_2$O can be described by a single exponential expression. Most water turnover studies describe the half-life of a tracer and/or a turnover rate calculated using this single exponential expression. When expressed quantitatively, it is calculated by the products of TBW and the turnover rate (Lifton and McClintock, 1966; Lane et al., 1997).

The previous studies of body water turnover limited to human studies are shown in Table 2, which presents the physical characteristics of subjects (physical activity level, sex, age) and methods of measuring body water turnover (techniques, tracer). In the following, we will review previous studies of body water turnover in terms of several key factors that seem to contribute to body water turnover.

### Body water turnover of children

Because it is difficult to administer tracers to and measure TBW in children, very few studies have been performed on body water turnover in children. To our knowledge, only one study based on direct measurement of daily water turnover exists. Fusch et al. (1993) measured body water turnover in 171 healthy children (88 girls, 83 boys, aged 6 weeks to 15 years) under normal living conditions. As shown in Table 3, daily water turnover decreased with age. Although they do not discuss this decline with age, it is clear that healthy children up to 15 years of age have higher water turnover than sedentary people do, as shown in Table 2.

### Aging and body water turnover

Cross-sectional studies demonstrate a diminution of TBW in elderly and very old subjects, and they indicate that the decrease in TBW is due mainly to decreased ICF (Shock et al., 1963; Fulop et al., 1985; Lesser and Markofsky, 1979). However, this is not supported by the findings of longitudinal studies (Steen et al., 1985). Thus, it is not clear if the decrease in TBW is due to a change in...
Exercise and body water turnover occur with age. That large individual differences in body water turnover in elderly subjects is uncertain. It is thought since Olsson (1970) did not publish the body water turnover cannot be established from these studies. Middle-aged people, and an age-related difference in body water homeostasis changes during aging. ECF, ICF, or both (Schoeller, 1989); however, it is certain that body water homeostasis changes during aging.

As described in Table 2, with the exception of the study by Olsson (1970), all studies investigated young to middle-aged people, and an age-related difference in body water turnover can not be established from these studies. Since Olsson (1970) did not publish the body water turnover data corresponding to subjects’ ages, water turnover in elderly subjects is uncertain. It is thought that large individual differences in body water turnover occur with age.

Exercise and body water turnover

Sufficient intensity and duration of exercise induces sweat production, which causes a loss of body water that must be replaced if euhydration is to be maintained. Loss of enough sweat to decrease body mass by only 3% can significantly diminish a person’s performance, and a rapid 5 to 10% decrease in body mass in this way can often be very serious, leading to muscle cramps, nausea, and other effects. On the other hand, a daily water gain of 10% is produced in our cells during metabolism, as water is a byproduct of oxidative phosphorylation. This metabolic water production varies depending on the rate of energy expenditure. These facts indicate that water balance is unstable and suggest that suitable hydration is needed by exercising people; however, very few studies linking exercise and/or physical fitness to water turnover have been carried out.

Leiper et al. (1996) assessed the effects of exercise habits on water turnover in endurance-trained middle-aged men. The investigators compared water turnover in exercising men who ran on average 14.8 km per day to that of the same-aged sedentary men. Body water turnover was higher in the exercise group than in the sedentary group. They also found that the fluid intake was greater in exercising men than in sedentary men, and suggested that the difference in volume is in excess of that fluid required for replacing exercise-induced sweat and respiratory water losses. Fusch et al. (1998) assessed water turnover and changes of body water during a trekking tour at moderate altitude. The mean TBW measured during trekking was significantly lower than the baseline value measured before the tour. Both parameters, loss of body water and increase in water turnover, were significantly correlated to the physical fitness levels of subjects: better trained subjects had higher water turnover and tolerated a larger loss of body water.

These studies indicate that a higher turnover rate and/or shorter half-life of tracer are expected in exercising people; however, it is still not clear how much training induces alterations in water turnover.

Environment and body water turnover

Human thermoregulation is controlled by the rate of blood flow in the skin, which controls the rate of sweating. This control system works according to environmental temperature and humidity. Under hot and humid condition, enough sweat is needed to maintain a suitable body temperature, indicating that water turnover may be influenced by factors relating to thermoregulation.

Sigh et al. (1989) reported that water turnover is 50 to 100% greater in tropical climate due to increased insensible water loss. Several investigators suggested that environmental factors such as altitude, season, and humidity may affect changes in water turnover (Foy and Schnieden, 1960; Wylie et al. 1963; Kaneko et al. 1985); however, these studies do not fully account for the correlation of water turnover with environmental factors.

A few studies were performed to assess water turnover in special environments. Lane et al. (1997) evaluated water turnover for short-term space flights (8 to 14 days) compared to ground-based periods. Water turnover and energy expenditure was lower during space flight than during the ground-based period. They discussed that lower fluid intake and perspiration loss during flight may affect the lower water turnover; however, they mentioned that water turnover could not be expected to increase if water intake were adequate.

**Table 3** Daily water turnover per body weight calculated from the data for nine age groups

<table>
<thead>
<tr>
<th>Age group (months)</th>
<th>Age group (years)</th>
<th>1–3</th>
<th>4–6</th>
<th>7–9</th>
<th>10–12</th>
<th>13–15</th>
</tr>
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<tbody>
<tr>
<td>Mean</td>
<td></td>
<td>160</td>
<td>119</td>
<td>114</td>
<td>97</td>
<td>64</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>34</td>
<td>19</td>
<td>27</td>
<td>29</td>
<td>21</td>
</tr>
<tr>
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<td>114</td>
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<td></td>
<td></td>
<td>46</td>
<td>40</td>
<td>39</td>
<td>13</td>
<td>7</td>
</tr>
</tbody>
</table>


**Body Water Turnover as an Indicator of Health**

Body composition assessment for evaluating human health status

Body composition has become a major field of interest for many exercise and sport scientists as well as clinicians who specialize in the prevention and rehabilitation of hypokinetic diseases (Wilmore, 1983). Numerous studies have focused on using human body composition to assess health status, and on changes in body composition with exercise and/or diet therapy.

However, a question remains about the continuing changes in total body mass and body composition as a person grows older. In general, although published equations are used in studies requiring an estimate of human body components, the aging process is neglected.
in body composition estimation in these studies. The methodology and popularity of body composition assessment has progressed in the past 50 years (Wilmore, 1983); however, because all the methods that have been developed during that period have been assessed indirectly, it is difficult to conclude that body composition is a suitable index of health status in elderly people.

The other hand, it seems that body composition variables, the amount of lean body mass (LBM) and/or fat mass, are assessed in a subject’s static condition. In the case of elderly people, because of large individual variations in each component of the body, it is necessary to assess the subjects metabolically or dynamically.

**Body water turnover as a new indicator of health**

Many indicators have been developed for evaluating human health status. In Japan and other developed countries, the percentage of older adults continues to increase. By the year 2025, the segment of society over age 65 will peak at approximately 23–26% in Japan. A significant goal of health science is to help extend the portion of the lifespan during which older people are active and in good health (Tanaka and Chodzko-Zajko, 1998), so it is important to develop an adequate and valid index for evaluating health status in elderly people.

Our discussion of body water turnover notes that further investigation is needed on the body water turnover levels associated with significant changes in physiological condition and metabolic state. Several factors may have a potential for affecting human body water turnover. For instance, healthy young children have a higher water turnover than adults do, and higher turnover rates and/or shorter half-life of tracers were seen in physically active people. However, it is not clear whether a slowing of body water turnover can be considered a risk factor for health disorders in the human body. In the case of elderly people, it is thought that there are large individual variations in body water turnover based on metabolic activity and that it is affected considerably by personal lifestyle. It is hypothesized that healthy individuals have a higher turnover than unhealthy individuals whose metabolic balance as indicated by body water turnover has broken down, and that a prolonged condition of excessively slow body water turnover may be associated with a negative physiological metabolic rate. That is to say, body water turnover, which indicates the dynamics of body water, can be a suitable metabolic indicator. Therefore, we propose that body water turnover is a significant indicator for human health status.

**References**


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