Free Flow of Sweat due to Loss of Surface Tension at Sweat Droplet Causes Water-Induced Skin Wrinkling

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Abstract: Sweat from the body is regulated by the surface tension of a sweat droplet at the pores and the pressure within the sweat duct. A sweat droplet grows in size until its surface tension and the pressure within the sweat duct are in equilibrium. When a hand is immersed in water, sweat droplets easily merge within the water, causing the pressure to drop at the pores. This in turn makes the sweat to flow freely into the water in the absence of counteracting pressure. Sweat glands produce more sweat because of the low pressure within the duct. To prevent loss of water from the body and to maintain the homeostasis, the body reacts by restricting the blood flow to the hand causing vasoconstriction and eventual wrinkling of the skin.

Keywords: water immersion skin wrinkling, sweating, surface tension, dehydration, homeostasis, vasoconstriction, Cystic Fibrosis.

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Introduction

Even though the water immersion skin wrinkling (WISW) of the palmar region is used as a test for sympathetic nerve functioning [1,2,3], the underlying cause of such a test was eluded for a long period of time. Many observations were made during this time for this very common phenomenon. Reduction of the blood flow to the immersed region and the resulting vasoconstriction was observed by Wilder-Smith and Chow [4] as the cause of skin wrinkling. The trigger to the sympathetic nervous system to reduce the flow of blood, when immersed in water, is remained as the unknown component of this riddle.

In the absence of satisfactory explanation, it was argued that the possible cause of skin wrinkling is due to the absorption of water through many of the sweat ducts. The subsequent alteration of epidermal electrolyte homeostasis results in increased firing of the surrounding neurons [5]. However, recent findings suggest abnormal flow of sweat during the wrinkling process. Excessive sweating, also known as Hyperhidrosis, is normally observed as part of the skin wrinkling process [6,7,8]. People with hyperhidrosis get more wrinkles on their hand in a short period of time when immersed in water. This indicates a possible relationship between the amount of sweat and the intensity of the wrinkles. Dilated sweat ducts [6,7], an increase in transepidermal water loss in the form of vapor [8], and the presence of excessive aquaporin 5 (AQP5) proteins in sweat glands [7] were also observed immediately after skin wrinkling. All these findings possibly suggest the flow of sweat towards the pores during the wrinkling process. However, the cause of the initiation of the flow of sweat is still unknown. Before delving further into the cause of the flow of water and wrinkling of the skin, it is necessary to revisit the process of sweating.

Why do we sweat?

It is a widely accepted phenomenon that the evaporation of sweat on the surface of the skin causes cooling of the body by absorbing the heat. The internal heat also escapes through respiration through the lungs and radiation from the surface of the skin.

During a period of intense physical activity, or being in proximity to hot environments, the temperature of the body increases more than these three known cooling processes together could possibly dissipate. Then, what is the mechanism that the body adopts during these instances to remove the excessive heat to protect the internal organs from overheating?

The common understanding of evaporation of sweat from the skin, as the only major mechanism by which the body cools down, is a misconception. During intense physical activity, such as playing a basketball game, the players profusely sweat during the course of the game. A very small amount of the total sweat gets evaporated from the skin compared to the amount of sweat that slides off the skin. The amount of sweat evaporated will not account for cooling the body temperature back to normal. In fact, most of the excessive heat within the blood escapes through sweating itself. By means of sweating, the body removes a certain amount of hot water from the blood.

Even though the temperature of the blood increases during an exercise, there will be a smaller amount of blood circulating within the body after sweating. Therefore, the amount of blood each of the internal organs receive in a given period of time also reduces, in turn minimizing the heat transfer between the blood and the organs. In this way, the body protects the internal organs from overheating by limiting the supply of overheated blood. Meanwhile, the three other cooling processes cool down the body temperature back to normal. Excessive sweating or dehydration during an intense physical activity is a mechanism to protect the internal organs from overheating. Therefore, sweating is a major part of the cooling mechanism of the body.

On the other hand, excessive sweating, in a resting body under normal conditions, removes a certain amount of warm water from the blood. Each of the internal organs receives a smaller amount of blood with a normal temperature. As a result, there will be a smaller amount of heat transfer between the blood and the organs. In this scenario, the temperature of the blood decreases with gradual depletion of the water from the blood.

Methods and Results

Water immersion skin wrinkling is a well observed and documented phenomenon. The only thing that needs to be explored is the direction of the flow of water across the barrier in the wrinkling process. To determine the direction of the flow of water, we did an informal experiment by dipping fingers, after a brief physical activity, into a plastic cup filled with instant coffee powder, the best water absorbing material available in the kitchen pantry. We selected six healthy subjects (2 males and 4 females) from the age at eight to 50 years old for the purpose of these experiments. We poured fresh coffee powder into each cup and asked the subjects to dip the fingers an inch into the powder. We observed the thickness of the coffee powder attached to the fingers after a period of 30 minutes.

For this experiment to work, there has to be a minimum amount of sweat at the pores, thats why we subjected each participant to a brief physical activity. The purpose of the experiment was to observe how much additional sweat diffused into the powder, other than the sweat already there at the pores. We observed that all the subjects displayed a thick layer of coffee powder stuck to their fingers, denoting a possible additional flow of sweat into the powder.

Discussion

The presence of a thick layer of coffee powder around fingers when dipped into coffee powder for 30 minutes after physical activity, possibly indicates an excessive secretion of sweat. Even though we didn't observe any significant amount of skin wrinkling, these results demonstrate that the rate of sweat increases when the hand comes in contact with a water absorbing material if there is already an existing sweat droplet at the pore. All the earlier work on skin wrinkling also suggests the association of WISW with hyperhidrosis [6,7,8]. Kabashima et al [7] reported that skin wrinkling was limited to the iodine-starch positive areas, suggesting that the hyperhidrosis plays a major role in skin wrinkling. Therefore, we could say that the formation of wrinkles involves excessive secretion of sweat when the hand comes in contact with, the best water absorbing material of all, water itself.

The secretion of sweat from the body is regulated by the surface tension of the sweat droplet at the pores and the pressure within the sweat duct. A sweat droplet grows in size until the surface tension of the droplet and the pressure within the sweat duct are equal. If there is no further increase in the pressure within the sweat duct, no further sweat is formed; unless the sweat droplet is wiped off the skin, adjoining sweat droplets merge and slide off the skin, or the sweat droplet is evaporated. When the sweat droplet is wiped off the skin, a new droplet starts to form at the pore until equilibrium is reached. During the period of intense physical activity, the pressure within the sweat duct increases due to the generation of new sweat at the glands. The increased pressure pushes the sweat outward.The droplets grow in size and merge with adjoining droplets to form as drops, eventually sliding off the skin due to increased weight. When the body is in rest, the pressure within the duct and the surface tension of the droplet will be in equilibrium. When a hand is immersed in water, sweat droplets easily merge within the water causing the pressure to drop at the pores. This in turn makes sweat to flow continuously into the water without any obstruction. It is similar to continuously wiping off the sweat from the skin in a super fast manner. The loss of water content from the blood as excessive sweat continues as long as there is a flow of blood to parts around the sweat glands.

As discussed earlier, the loss of water in a stationary and resting subject is an abnormal condition, which gradually cools down the temperature of the body. To maintain the homeostasis of the body, the nervous system triggers the reduction of blood flow to the palmar region, causing vasoconstriction [4]. The skin wrinkles due to the loss of volume under the skin.

Granulated and porous material, like coffee powder, can also absorb the sweat similar to the scenario where the hand is immersed in water. When granules of dry coffee powder come in contact with the tiny droplets of sweat at the pores, they quickly absorb the sweat. Because of the lack of convective system, sweat percolates into the powder rather slowly. Eventually, enough sweat will be absorbed, over a period of 30 minutes, to form a thick layer of coffee around the fingers.

The association of the dilation of sweat ducts and hyperhidrosis with WISW, along with the possible excessive sweating in a water absorbing material indicates that the formation of wrinkles involves the flow of water from inside out, not the absorption of water from outside. The reason for wrinkles to form on the palm is that it has more sweat pores than any other part of the body [9]. More pores causes more sweat and faster depletion of water from the body, and faster formation of dense wrinkles. For the sweat to deplete from the hand, when immersed in water, there has to be a minimum amount of sweat at the pores. In essence, the depletion of water from the sweat channel, when immersed in water, accelerates if there is an existing droplet at the pore.

The leading edge of the sweat could cause counter pressure and be in equilibrium with the pressure at the glands, even if it is not at the pore. In this scenario, the formation of wrinkles will be minimum because of the possibility of an air bubble between the sweat and the water. A slight physical activity creates droplets at the pores and that could accelerate the formation of wrinkles.

Cales and Weber [10] reported that the optimal temperature for testing skin wrinkling on hands is 40^{o} C. Increased temperature of the water reduces the pressure it exerts, causing the sweat at the pore to merge with the water faster. In contrast, cold water exerts more pressure causing the sweat to merge rather slowly. Tsai and Kirkham [11] noted that the increased tonicity significantly slowed the time to wrinkling. Increased tonicity of the water increases the pressure the solution exerts causing the sweat at the pore to merge with the water slowly.

All the previous work showed that wrinkles form on the hand faster when placed under running water, like taking a shower or washing hands under a tap, than placing hands in a bucket full of stationary water of same temperature. Flowing water strips away sweat droplets on the pores as soon as they form. Moreover, the remaining sweat in the duct flows faster into the water flow because of the low pressure created in the flowing water. According to the Bernoulli principle of fluid dynamics, the faster the movement of the fluid, the smaller the pressure it creates in the flow. The sweat glands produce more sweat to replenish the loss in the duct. This continuous process of generation of sweat at the glands and merger of sweat into the water at the pores, depletes the water content of the blood faster than stationary water. A faster response from the nervous system, and subsequent vasoconstriction, causes the skin to wrinkle faster than the stationary water.

We believe that it is possible to explain all other scenarios where wrinkles occur using the work presented in this paper. The whitish papules and plaques formed during the wrinkling of the skin, as reported by Neri et al [5], are possibly the result of high pressure sweat in the duct pushing the skin outward, disconnecting the upper layer of the skin from it's base. The observation of each of the papules with a puncta at the middle, right on top of the pores, supports this case.

It was also observed that the onset of Cystic Fibrosis causes hyperhidrosis [8,12] and aquagenic skin wrinkling. Possibly, patients with Cystic Fibrosis sweat a lot because of the partial blockage of the trachea. The loss of heat from lungs through exhaling water vapor diminishes due to the blockage of the respiratory tracts. To compensate the reduced cooling of the body through exhaling, the body overloads the sweat glands to produce more sweat to cool down the body. This is why we see hyperhidrosis, and the related WISW in most of the patients with Cystic Fibrosis. Hyperhidrosis disappears after the cure from Cystic Fibrosis because of the clearing of the respiratory tracts for proper exhaling and the return of normal functioning of the sweat glands.

Prolonged exposure to water causes dehydration and expands the plaques to all of the exposed palmar skin. The resulting reduction in blood flow limits the supply of oxygen and nutrients to the fingers. Altogether, the process of wrinkling appears to be a protective mechanism of the body to control the temperature. Wrinkles may be advantageous to the hand in handling objects in wet environments [13] for a short period of time, sometime between the onset of wrinkles and the formation of plaques. It is certainly not advantageous to the hand after the formation of plaques. The theory of wrinkles as an evolutionary advantage as primate rain treads [14] for handling objects in wet environments seems implausible.

Conclusion

Water immersion skin wrinkling as a test for the sympathetic nerve functioning works only when the subject has a sufficient number of normally functioning sweat channels on the palms. The free flow of sweat when immersed in water is essential in skin wrinkling. The presence of existing droplets at the pores is also important in initiating the free flow of sweat. The time taken for the wrinkles to form depends upon how fast the material, in which the hand is immersed, absorbs the sweat. Depletion of water from the blood destabilizes the homeostasis, triggering the reduction in blood flow to the hand and subsequent skin wrinkling on palms. De-nerved fingers do not sweat [1] because they lack the response for the pressure changes at sweat glands and within sweat ducts. Therefore, there wouldn't be any excessive sweat in these fingers when immersed in water. Wrinkles wouldn't appear on these fingers because of the absence of vasoconstriction. We believe further exploration on these lines will shed more light on this intriguing phenomenon.

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