ANTI-AGING MEDICINE

Received: Feb. 10, 2010
Accepted: Mar. 8, 2010
Published online: May. 11, 2010

Review Article

Odor Associated with Aging

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Abstract

Human body odor is generated by waste materials present on the skin surface and secretions from the sweat and sebaceous glands. These waste materials are converted to characteristic odorous compounds through oxidative degradation or metabolism by skin microbes. Changes in body odor due to aging relate to the amount and composition of sweat and sebum secreted, as well as gland activity. 2-Nonenal has an unpleasant, greasy, grassy odor and is mainly detected in people aged over 40 years. Generation of 2-nonenal is related to oxidative degradation of $\omega 7$ unsaturated fatty acids. Given that body odor may function as a barometer indicating the body's overall health, further understanding of this odor's makeup is important. Here, we define several types of body odor and describe changes in body odor, with a specific focus on 2-nonenal, an odor characteristically associated with aging.

KEY WORDS: aging, body odor, nonenal, sweat, sebum

Introduction

In recent years, many people have become increasingly conscious of odor and have become very sensitive to smell. The most familiar smell is our personal odor; that is, the odor generated by our own bodies. Body odor is known to vary by individual with regard to strength and quality, and given that this odor is associated with a negative impression, humans are typically keen to eliminate or reduce its noticeability. However, body odor is an important signal that can indicate a person's state of cleanliness and overall physical condition. Various factors such as gender, eating habits, living environment, and race can all affect body odor. Here, we assessed the effect of aging on body odor by examining evidence presented thus far.

Body Odor

Smells typically regarded as "body odor" can be divided into two types: those originating from the whole body, such as sweat glands and the skin surface, and those originating from a specific part of the body, such as foul breath, head odor, armpit odor, and sole. In many cases, body odor is perceived as a combination of several odors. Odors emanating from a specific part of the body tend to exhibit characteristic odors, which will be examined here.

Common factors contributing to body odor are secretion by the skin's sebaceous and sweat glands and waste product plaque from the stratum corneum. Metabolism of these compounds by bacterial flora in the skin or by atmospheric oxidation subsequently produces a volatile malodor. Body odor is primarily comprised of low-molecular-weight fatty acids, chiefly aldehydes, ketones, nitrogen-containing compounds, and sulfur compounds [1)].

Below, we describe body odor generated in specific parts of the body, after which we will describe changes in body odor due to aging.

Odor from Sweat

Like many mammals, humans sweat as a means of thermoregulation, to prevent body temperature elevation when heat is generated by strenuous activity. Unless removed from the body by some means, sweat left to sit can produce a strong odor, contributing heavily to the scent known as body odor.

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Human skin contains two kinds of sweat glands: eccrine and apocrine glands. Eccrine glands, which are distributed throughout the body, are charged with functions such as heat regulation. Immediately after secretion, most sweat is odorless, and 99% of the liquid is water, with a small amount of inorganic salt, lactic acid, and amino acids.

The smell of sweat generally originates when secreted sweat is metabolized by skin bacteria. Sawano *et al.* examined sweat from a healthy man, assuming lactic acid to be a principal ingredient, and detected low-molecular-weight fatty acids such as acetic acid, propionic acid, isobutyric acid, butyric acid, and isovaleric acid [2]. In a previous study, when skin bacteria such as *Staphylococcus epdermidis var., S. aureus, Corynebacterium minutissimum, and Arthrobacter sp.* were placed into sweat samples and cultured, a sweat-like odor was generated from the acidified culture medium containing *Staphylococcus epdermidis and S. aureus* [3].

Underarm Odor

In contrast to the to rather ubiquitous eccrine glands, apocrine glands are found in only specific parts of the body, such as the armpit, mammary areola, and genitalia [1]. Sweat secreted from apocrine glands is comprised primarily of water as well as proteins, lipids, fatty acids, cholesterols, and iron-containing salts. Armpit odor is particularly pungent because, in addition to apocrine glands, eccrine and hair glands are also present. Further, bacilli are quite populous in the armpits (***Table 1***) [4].

Table 1 Number of bacteria detected in human skin

	Number/cm^2	Range
Head	1.46×10^6	$0.22\text{-}14.3\times10^6$
Armpits	2.41×10^6	$6.3\times10^2\text{-}16.7\times10^6$
Forearm	4.50×10^2	$4.0\times10^2\text{-}1.9\times10^4$
Back	3.10×10^2	$5.0\times10\text{-}1.45\times10^3$
Forehead	0.20×10^6	$0.03\times10^6\text{-}0.55\times10^6$

Armpit odor is often recognized as the main component of body odor and has been the focus of odor analyses by many researchers. For example, Brooksbank *et al.* examined an absorbent cotton pad which had been placed in the armpits of 12 men and confirmed the presence of a small amount of androstenol, a volatile steroid [5]. Other compounds detected at the pmol level included androstenone, 5α-androst-16-ene-3α-ol, 5α-androst-16-ene-3 β-ol, and androsta-4, 16-dien-3-one, which are androst-16-ene derivatives. Many of these volatile steroids give off a malodor characterized as musk-like and associated with the scent of urine, and 5α-androst-16-ene-3α-ol and 5α-androst-16-ene-3β-ol are pheromones found in male pigs. Volatile steroids are typically found in higher concentrations in the bodies of men than in women [6], and a sexual difference in receptivity to volatile steroids has been reported. Further, these steroids have a reinforcing effect on body odor strength [7,8].

In contrast to these previous findings, analysis by Sawano and Zeng on the odor generated from a man's armpit noted a peculiar, animal-like body odor, and found levels of the fatty acid (E)-3-methyl-2-hexenoic acid (3M2H) [2,9]. Further, 3M2H was identified in samples derived culture of an odorless apocrine secretion with *Corynebacterium*, suggesting the involvement of *Corynebacterium* in the generation of this fatty acid [2].

In their study, Ogura *et al.* focused on the spicy cumin-like smell found in some body odor samples. Examination of a pad sewn to the armpit of a t-shirt worn by a healthy Japanese man for 24 hours showed the presence of 3-hydroxy-3-methylhexanoic acid, which was subsequently reported to be a contributing factor to body odor [10]. Yabuki et al. also identified this odor in their unrelated study conducted at the same time [11]. This compound is known to be an optically active substance with an enantiomer ratio of S:R=72%:28%. The R enantiomer produces a smell reminiscent of fat, while the S enantiomer gives a spicy smell associated with armpit odor (***Table 2***).

Table 2 Characteristics of 3-hydroxy-3-methylhxanoic acid

Configuration	Odor type	Threshold in mineral oil (ppm)
S (+)	spicy, animalic, green	0.1
R (–)	fatty, woody, animalic	10

In addition, Yabuki *et al.* also analyzed sweat samples from the armpits of study participants who generated body odor in response to heat stimulation. Analysis revealed the presence of 3-mercapto-3-methylhexan-1-ol (11), an optically active substance with an enantiomer ratio of S:R=72%:28%. The R enantiomer was found to have a fruity and grassy odor, while the S enantiomer had a meat-like fishy odor similar to armpit odor (***Table 3***). Of particular interest was the fact that the enantiomer ratio of 3-mercapto-3-methylhexan-1-ol was the same as that of 3-hydroxy-3-methylhxanoic acid mentioned above. These findings may aid in determining the mechanism behind body odor generation.

Table 3 Characteristics of 3-mercapto-3-methylhexan-1-ol

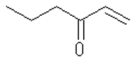
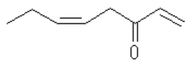
Configuration	Odor type	Threshold in mineral oil (ppm)
S (–)	meat-like, fruity, green	0.01
R (+)	green, citrus, fruity	0.01

Vinyl ketones have been suggested to be potential odorous components contributing to armpit odor. Iida *et al.* focused on a pungent odor found to stimulate the nose which was derived from sweat from a gauze strip sewn to the armpit of t-shirts worn for 24 hours by 66 male participants [12]. Analysis identified the vinyl ketones 1-octen-3-one (OEO) and *cis*-1,5-octadien-3-one (ODO), both of which are diffusive and have an extremely strong metallic smell with a low odor threshold (***Table 4***). The vinyl ketone generation mechanism is described in ***Fig. 1***. Briefly, unsaturated fatty acids in human metabolites come into contact with iron in the apocrine glands, forming a lipid peroxide. The lipid peroxide is changed to vinyl ketones by oxidative degradation.

Odor from the Skin and Hair of the Head

Sebum glands are distributed at high density in the scalp. Lipid concentrations are also high [13]. Scalp odor is generated by activity between lipids and two kinds of skin bacteria: P*ityrosporum ovale lives* and *Propiobacterium acnes*. *Propiobacterium acnes* exerts lipase activity, hydrolyzing glycerides derived from epidermal

Table 4　Characteristics of vinyl ketones of 1-octen-3-one and cis-1,5-octadien-3-one

	1-octen-3-one（OEO）	*cis*-1,5-octadien-3-one（ODO）
Chemical structure		
Odor type	metallic, mushroom-like	metallic, mold-like
Odor threshold (µg/kg)	0.05	0.0012

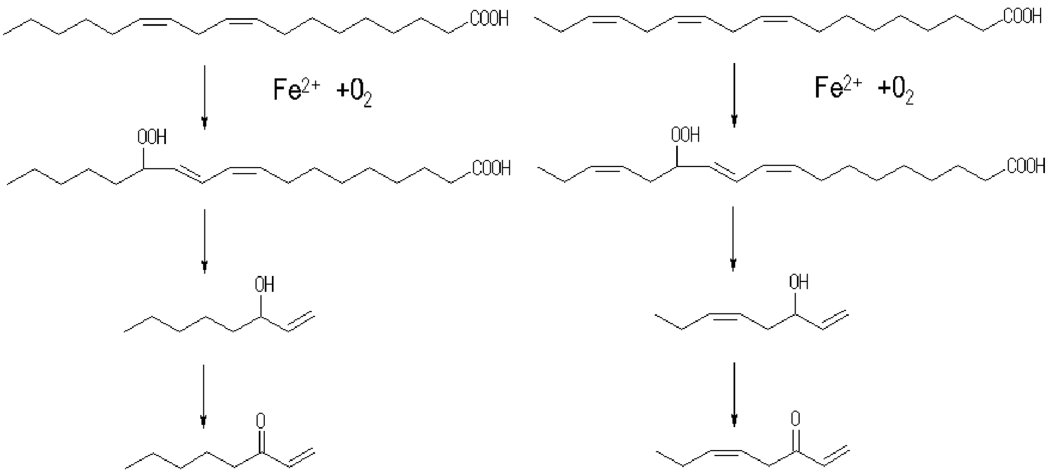


Fig. 1. Vinyl ketone generation mechanism [12]

tissue and sebum glands and generating long-chain fatty acids. In contrast, *Pityrosporum ovale* converts long-chain fatty acids into volatile ketones and lactones.

Using headspace gas chromatography, Goetz *et al.* analyzed volatile organic compounds derived from the scalp and hair, identifying 50 elements, including aldehydes, ketones, fatty acids, and lactones [14]. Kubota *et al.* also analyzed headspace gas and acetone extracts derived from scalp lipids, identifying isovaleric acid, isobutyric acid, pentanoic acid, hexanoic acid, valeraldehyde, heptanal, and indole as odorous components of head odor [15].

Foot Odor

Most humans spend a large portion of their daily lives wearing shoes. This environment, in which a moderate temperature and humidity are maintained, is ideal for the growth of skin flora bacteria, which metabolize the sweat and waste matter shed from the sole of the foot, generating foot odor. In their study, Kanda *et al.* conducted gas chromatography-mass spectrometry (GC/MS) analysis on samples obtained from the socks of participants with and without strong foot odor. Results showed high levels of low-molecular-weight fatty acids in participants with strong foot odor. Further, they reported that isovaleric acid was found to be the main cause of foot odor [16].

Age-Associated Odor Compound

Advances in medical treatment have extended average life span, and in recent years, the population of those aged 65 and older has come to account for 15% or more of the total population. In response to this aging population, focus has recently turned to describing the odors generated with age.

A survey on people's attitudes toward body odor was administered to participants aged between 20 and 70 years. A total of 98% responded that they felt anxious about their personal body odor in their daily lives and were concerned about the body odor of others [17]. With regard to specific odors of concern, 19.9% responded with sweat, 16.8% with personal or others' body odor, 13.3% with scalp hair odor, 10.7% with body odor of the elderly and armpit odor, and 9.7% with a general unclean odor. Further, group interviews conducted among women in their 20s generated many comments that middle-aged and elderly people, particularly men, have a specific, unpleasant odor. Interviews conducted among 150 men and women aged between 40 and 60 showed that 23% of men and 44% of women felt that their body odor had changed with age, suggesting that recognition of a change in body odor due to aging does indeed exist.

To clarify the presence of an age-associated odor, Haze *et al.* analyzed the headspace gas of undershirts obtained from 22 healthy men and women aged between 26 and 75 years after the shirt was worn overnight for straight three evenings [18]. GC/MS subsequently identified hydrocarbons, alcohols, acids, and ketones as odorous components (***Table 5***). Of particular note is that 2-nonenal, an unsaturated aldehyde, was not detected at all in participants aged less than 40 years, but was detected in 69% of

Table 5 ***Compounds detected in body odor by gas chromatography-mass spectrometry analysis***

Compounds	**Detection rate (%)** In patients <40 years old (n=9)	In patients ≥40 years old (n=13)
Hydrocarbons		
1-Octene	11	8
Decane	11	23
Undecane	22	23
Dodecane	67	69
Alcohols		
1-Butanol	11	8
1-Heaxnol	11	15
2-Ethylhexanol	89	85
Octanol	11	8
1-Decanol	11	15
Amyl alcohol	11	8
Hexadceanol	11	8
Octadecanol	11	8
Acids		
Acetic acid	22	23
Butyric acid	22	15
Ketones		
4-Methyl-2-pentanone	11	8
6-Methyl-5-heptenone	89	77
Aldehydes		
Hexanal	33	23
Heptanal	11	15
Octanal	89	85
Nonanal	89	85
Decanal	89	69
2-Nonenal	0	69

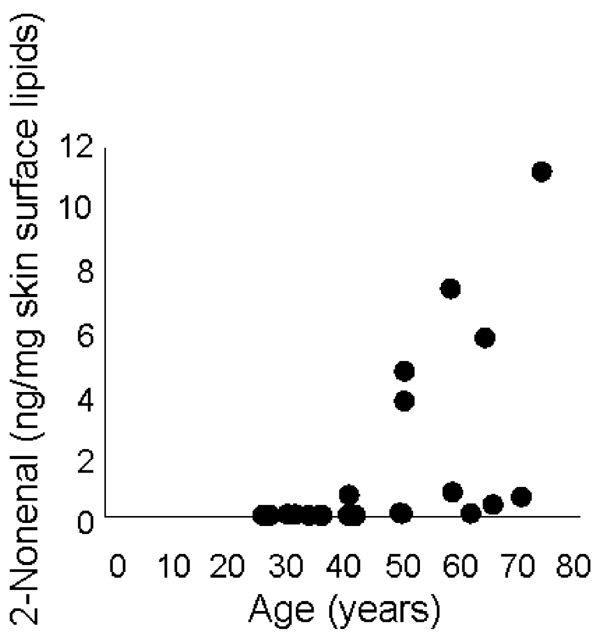


Fig. 2. Change of 2-nonenal in the skin surface lipids with aging [18]

participants aged 40 years or more (***Table 5, Fig. 2***). The odor of 2-nonenal was characterized as similar to old pomade and candle wax, having a fishy or resin-like odor, and is believed to be the key element in odors associated with aging.

Unlike the sweat-related body odor observed in younger people, odors in the elderly are often associated with the aging body itself. The main causative agent of this "aging odor" is sweat and sebum, with the point of origin is believed to be the sebum glands, based on the odor's characteristics.

ω10 unsaturated fatty acids were found in sebum samples from most of the study participants, with ω7 unsaturated fatty acids particularly high in middle-aged and elderly participants. ω10 unsaturated fatty acids are known to increase with age, as shown by plotting the ratio of ω7 to ω10 (***Fig. 3***). Concentration of hyperoxidation lipids in sebum has been confirmed to increase with aging. In their report, Hayakawa *et al.* found that the ratio of peroxide to total lipids gradually increased with age, with the lowest value observed among participants in their 20s [19]. Further, a positive correlation was noted between the ratio of ω7 to ω10 unsaturated fatty acids in the sebum and the amount of 2-nonenal detected in the body odor (***Fig. 4***).

Sawano hypothesized that unsaturated fatty acids secreted on the body surface generated the aging odor by being oxidized by the air and metabolized by skin flora bacteria. This hypothesis was subsequently tested by oxidizing and metabolizing palmitoleic acid [2]; after oxidation and aeration for 16 days, the sample was found to have an odor reminiscent of old pomade, differing starkly from the oil-like malodor detected by the sensory test before oxidation.

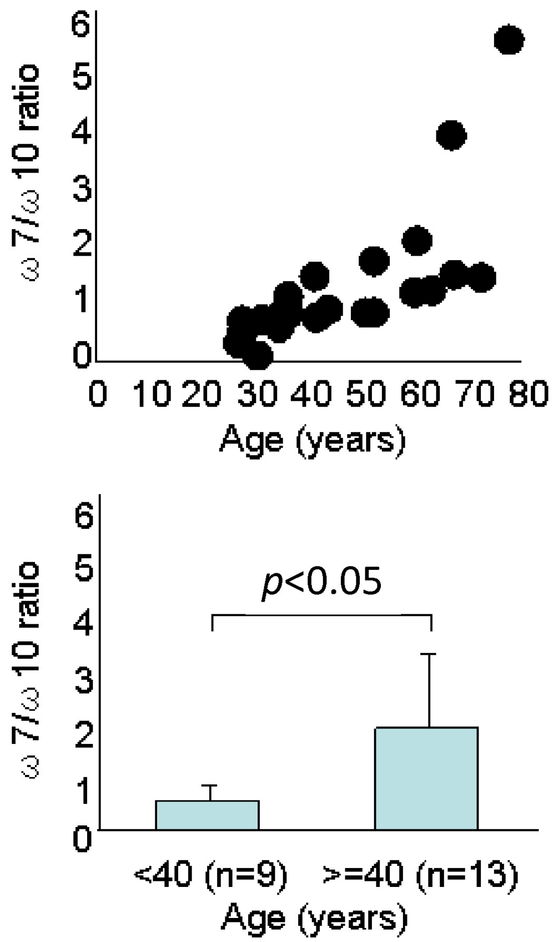


Fig. 3. Effect of aging on the quantitative ratio of ω7 monounsaturated fatty acids to ω10 monounsaturated fatty acids [18]

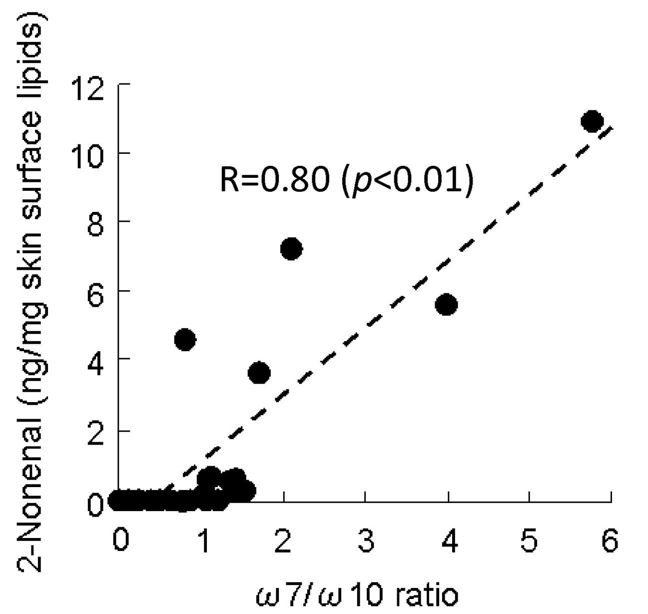


Fig. 4. Relationship between the amount of 2-nonenal among skin surface lipids and the quantitative ratio of ω7 monounsaturated fatty acids to ω10 monounsaturated fatty acids [18]

GC/MS analysis detected aldehydes such as 2-nonenal, fatty acids such as butyric and valeric acid, and low-molecular-weight fatty alcohols.

When palmitoleic acid was added as a substrate to culture medium of various species of skin flora bacteria, aging odors were confirmed in cultures containing *Staphylococcus epdermidis*, and subsequent GC/MS analysis of the extracted material revealed the presence of 2-nonenal. Based on these results, a model smell of aging odors was constructed, using 2-nonenal as a key element; assessment of the odor found that the mix smelled strongly of aging odor. Taken together, these findings indicated that 2-nonenal is indeed the main odorous component of aging odor.

Generally, lipid oxidation is initiated when lipids, including unsaturated fatty acids, are left standing at room temperature, leading to hydroperoxide (HPO) generation. Once the lag phase is completed, peroxide concentration increases rapidly, and HPO is generated as a chain reaction. Resolution starts when HPO accumulates and low molecular weight fatty acids and aldehydes are generated, thereby increasing odor strength. This same generation mechanism is believed to contribute to the generation of aging odors [2].

No detailed report has yet been published concerning the influence of aging on skin flora bacteria, and thus the relationship between skin flora bacteria and aging odor generation remains unclear.

Changes in Odor Due to Aging

While 2-nonenal is indeed a major contributing element to age-related changes in body odor, consideration must also be given to odorous components in the skin itself.

In their study, Gallagher *et al.* analyzed the sebum and other odorous components of the skin on the upper back and upper arms of 25 healthy participants, identifying some 100 different volatile odorous components [20]. Data from the participants were divided into two categories: values from participants aged less than 41 years, and values from those aged 41 years and older. Results showed that the ratio of dimethylsulphone, a sulfated compound, was higher in the upper back skin of older participants than younger ones. Further, benzothiazole concentration was higher in both the upper back and upper arm skin in the older group than in the younger group. However, given that the difference in amount was only slight, the odor strength of these two compounds in these two age groups is estimated to be closely similar. Gallagher *et al.* concluded that there are only small differences in volatile organic compounds from the skin related to age. Such a change may in future be used as a biomarker rather than simply as an ostensibly detected odor.

Several studies have examined body odor elements generated by a specific age group. For example, Hirabayashi *et al.* analyzed the quality and strength of odor components obtained from the armpits and body trunk of 148 males aged between 10 and 79 years, after they wore the same shirt for 14 hours straight [21]. Results showed no significant difference by age in the strength of odor. Concerning the quality of odor, however, they noted a “peculiar oily odor” in males in their 30s which differed noticeably from those observed in both younger and older generations. Analysis of this odor revealed the primary component to be nonanoic acid, which smells similar to old cooking oil .

Sebum gland distribution in men peaks in the 30s, and hair glands are distributed throughout the trunk of the body. The observed increase in nonanoic acid generation is therefore believed to be due to oxidation of sebum into nonanoic acid.

Conclusion

Here, we have described the mechanism behind the generation of body odor. Causative agents have been determined to be waste matter on the skin’s surface and secretions from sweat glands and hair glands. These materials and compounds are subjected to oxidative dissolution by lipid peroxides contained in skin lipids and metabolism by skin flora bacteria, until eventually the generated volatile material gives off a malodor. Changes in body odor due to aging are thus directly related to changes in sweat gland activity and sebum composition, and indirectly to changes in food intake composition and increasing or decreasing amounts of physical activity. For these reasons, body odor is believed to function as a barometer for one’s physical condition at a given age.

Strengthening of body odor can indicate a lack of stability in food intake, uncleanliness, or any of a range of mental disorders. Under such conditions, therefore, we should seek to improve nutrition to promote health, keep the living environment adequately clean, and maintain a pleasant personal odor, as good smells are known to be both mentally and physically relaxing. However, aiming for excessive cleanliness or odorlessness may in turn reduce the sebum content and skin flora bacteria that perform otherwise essential, useful roles in maintenance of the skin. Such action may lead to a deterioration in skin condition and skin-related immunity measures. A moderate sense of balance with regard to regulating body odor should therefore be maintained. Dealing with age-related changes in body odor means creating an age-appropriate air. Adjusting personal body odor with fragrance and improving one’s overall appearance is believed to have a positive influence on personal hygiene and mental health, and is thus recommended.

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