50. Individual Variation in Body Odor

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Humans produce numerous volatile compounds from different areas of the body, either as a direct result of metabolic processes or indirectly via metabolism of resident microflora. Body odors vary between individuals, partly due to genetic differences, but odors of the same individual also vary across time due to environmental influences. We discuss how at least part of the genetic influence appears to be related to certain personality characteristics and to sexual orientation. We then review the current state of the art in terms of intraindividual variation, including effects of intrinsic factors, such as hormonal influences on body odor and environmental factors, namely effects of diet and certain diseases. Some of these changes can be perceived by other individuals and might therefore provide social cues of current motivational, nutritional, and health status. Finally, we discuss how specific odor profiles associated with certain infectious diseases and metabolic disorders can be used as a cheap and efficient medical screening tool.

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In common with other animals, humans constantly produce a cloud of volatile chemicals which can potentially be perceived by others. The majority of these compounds are direct by-products of body metabolism or products of the metabolism of either commensal or pathogenic microflora. Human body odors are emitted from various areas of the body notably from the mouth, the anogenital region, the scalp, and the axillae. In healthy adults, axillary odor appears to be the most distinctive, due to a relatively high concentration of both eccrine and apocrine glands in this area. Interestingly, most compounds in fresh apocrine sweat are odorless and these are converted to odoriferous molecules by the action of the residential bacterial microflora (Chap. 48). Body odor appears to be individually specific and relatively stable [50.1], perhaps due to genetic influences. This is supported by three lines of evidence:

1. Body odor of monozygotic twins show high resemblance [50.2].

2. Unacquainted individuals can match relatives (e.g., offspring and parents) based solely on body odor [50.3].

3. People show odor preferences associated with the genes of the major histocompatibility complex [50.4].

Further, people can identify others based on their body odor (for details of this kind of evidence, see Chap. 51). Apart from genetic influences, there are also numerous intrinsic and extrinsic factors shaping individual variation in human body odor. Here, we first review two factors contributing to interindividual odor variation, namely personality factors and sexual orientation. We then turn our attention to intrinsic factors of intraindividual variation in body odor, namely hormonal influence (emotion-related fluctuations in body odor are reviewed elsewhere; see Chap. 49), and to environmental factors, such as effects of diet and disease.

50.1 Personality

People tend to spontaneously attribute a range of psychological characteristics to others based simply on their appearance or on *thin slices* of their behavior. At least in some characteristics, such attributions are to some extent accurate; that is, they correlate with the target's personality profile. These attributions have been described as having a *kernel of truth* [50.5, 6]. Although less well-known, body odor could also contribute to such attributions based on first impression, as some personality traits are correlated with social perception of body odor. For example, women in the fertile phase of their menstrual cycle find the axillary odor of relatively dominant men more attractive [50.7], and in a series of studies it was recently shown that strangers can accurately attribute levels of neuroticism and dominance in others based solely on their axillary odor with women showing more accurate judgments compared to men [50.8, 9]. Furthermore, prepubertal children can accurately judge neuroticism [50.10]. The precise mechanism responsible for the association between personality traits and axillary odor quality is not well understood. In the case of dominance, both traits may be underpinned by levels of testosterone. The picture might be more complex in the case of neuroticism, but a potential indication lies in the observation that some emotional states (anxiety) have impact on odor quality and in turn affect other people exposed to such odors [50.11, 12]; as neurotic individuals tend to be more frequently distressed, this might also affect their body odor.

50.2 Sexual Orientation

The effects of one's sexual orientation extend beyond the sex of preferred romantic partners. There is robust evidence that it also influences various psychological (e.g., verbal fluency [50.13]) and morphological characteristics (e.g., second to fourth digit ratio, which is considered a marker of prenatal exposure to testosterone [50.14]), perhaps due to shared biological machinery, such as prenatal exposure to the level of androgens [50.15]. Several studies have consequently tested whether sexual orientation also has an impact on the quality of body odor, although results of these studies are somewhat inconsistent. In one study, odor samples taken from both heterosexual and homosexual men and women were judged for pleasantness by groups of heterosexual and homosexual men and women. There was a complex pattern of significant between group differences, although one relatively consistent pattern emerged: All groups except homosexual men showed lower preference for the odor of homosexual men [50.16]. In contrast, another study, which tested only the preferences of heterosexual women, reported that they found the odor of homosexual men more, not less, appealing than those of heterosexual men [50.17]. We therefore await further research before being able to draw sharp conclusions on this fascinating topic. Furthermore, the underlying mechanism linking sexual orientation and the quality of body odor is currently unknown.

50.3 Hormonal Influences

The endocrine system controls a very wide range of physiological processes and contributes to the motivation systems. Hormonal action can thus also influence body odor quality, either as a by-product of hormonal metabolism or by metabolism of the affected tissue. Furthermore, hormonal action might also target the apocrine glands in order to directly communicate motivational state to other individuals. The main focus of research on endocrine influences on body odor has been on steroid hormones.

In women, for example, there is relatively robust evidence showing that attractiveness of axillary body odor rated by men varies across the menstrual cycle, peaking in the follicular phase when the probability of conception is highest [50.18, 19]. No such changes are observed in women using hormonal contraception, suggesting that this effect is steroid hormone dependent [50.20], presumably as a result of changing amounts or ratios of estrogen and progesterone. One early study also found significantly higher pleasantness of vaginal odor in the follicular phase of the cycle [50.21]. Although the magnitude of these cyclic changes is substantially lower than the differences in odor attractiveness among individual women [50.22], they are nonetheless perceivable and might play a role in coordinating sexual activity. In line with this idea,

men exposed to women's axillary odors collected during the fertile phase of the cycle experience elevated levels of testosterone [50.23, 24] although another study was not able to replicate this effect [50.25]. Similar increases in testosterone and cortisol are invoked by vulvar odor collected in the women's fertile phase [50.26]. In a series of follow-up studies, it was found that exposure to fertile phase axillary odors specifically activates mating-related concepts in men (e.g., generating more sexually tinged words), increases their judgments of women's sexual arousal, and leads to more risky decisions (assessed by a computerized blackjack card game) [50.23]. Furthermore, women seem to be similarly reactive to fertility-related odors as they showed increased testosterone levels after exposure, although this is presumably a consequence of intrasexual competition rather than attraction [50.27].

One might also expect changes in body odor related to pregnancy, based on the specific hormonal profiles which occur during this time. This includes elevated levels of human chorionic gonadotropin during the first trimester and continuously rising levels of progesterone and estrogens during the course of pregnancy. In one study, several specific compounds were detected in axillary and areolar samples taken from pregnant women. Some of these were also found in lactating women after delivery, but not in a control group of nonpregnant women. Two of the identified chemicals, 1-dodecanol and oxybis octane, showed systematic fluctuations during the pregnancy [50.28]. Furthermore, changes in breath volatiles of pregnant women have been found using an electronic nose, although no specific compounds related to pregnancy were identified [50.29]. These analytical results are also supported by subjective ratings, such that men rate axillary odor of women in the second trimester as most pleasant [50.30]. Finally, several studies on attractiveness of human body odor to mosquitoes showed higher bite rates in pregnant women [50.31–33]. Interestingly, the attractiveness of body odors to mosquitoes appears to be affected by levels of short-chain fatty acids, and this might explain higher bite rates observed in pregnant women [50.34].

In contrast, investigations into potential links between the quality of body odor and levels of other hormones present more inconsistent results. In one study, it was found that attractiveness of axillary body odor is positively associated with cortisol levels but not with testosterone [50.35]. Another study, based on a larger sample of both odor donors and raters, showed that males whose odor samples were judged as attractive show higher levels of testosterone but not cortisol [50.36]. Finally, one more study found a negative association with cortisol levels [50.37]. Thus, clearly it is currently difficult to draw any robust conclusions on relationships between these steroid hormones and odor, and further investigations of potentially modulating factors responsible for these inconsistent findings are required.

50.4 Diet

Some authors consider diet as the most salient environmental factor shaping our body odor as humans consume a high variety of aromatic foods [50.38]. Several volatile compounds may subsequently emanate in breath odor. Further, some components of the diet might produce volatile compounds only after being metabolized by the digestive system. As volatile molecules are relatively small, they can pass through the epithelium and be distributed across the body via the blood stream. In this way, they can consequently affect axillary odor or odor of urine and feces. The studies on effect of diet are summarized in Table 50.1.

Evidence from animal studies indicates that diet might be a potent modulator of body odor and that in some species, females can use odor cues to assess the quality of potential mates by the quantity and quality of ingested food. *Pierce* and *Ferkin* [50.49] investigated the effect of food deprivation on odor of female meadow voles (*Microtus pennsylvanicus*). It was shown that the odor of starving animals was less attractive compared to individuals fed *ad libitum*. This effect disappeared 48 h after re-feeding. The crucial factor for nutrition appears to be not only the availability of food, but also its quality, such as the amount of dietary protein. It was found that both male and female meadow voles preferred the odor of opposite-sex individuals on a high-protein diet, and spent the least time investigating the odor of individuals on a low protein diet [50.50]. Similarly, attractiveness of urine odor was positively linked to high quality food in guinea pigs (*Cavia porcellus*) [50.51]. In an analogous manner, red-backed salamander (*Plethodon cinereus*) females assess territory quality by examination of male fecal pellets and prefer pellets from individuals fed on high-quality food [50.52]. Other social interactions might be affected by diet as well. For instance, in spiny mouse (*Acomys cahirinus*) pups, preferences are formed early in life, and they subsequently prefer the odor of females fed on the same diet as their mothers [50.53].

The effect of diet on human body odor was first demonstrated in twin studies. Humans were able to discriminate the hand odors of monozygotic twins on

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Table 50.1 Summary of studies on effect of diet on human bodily odors

Authors	Food	Odor source	Odor quality/hedonicity	Volatile compound(s)
Fialová et al. [50.39]	Garlic	Axilla	↑ Attractiveness, pleasantness, ↓ intensity	
Hauser et al. [50.40]	*Amba* (mango, saffron, curry)	Skin, amniotic fluid	Foul, curry	
Hauser et al. [50.40]	*Khilba* (fenugreek)	Skin	Fenugreek	
Hauser et al. [50.40]	*Shug* (cumin, garlic, salt, oil, pepper)	Skin	Cumin	
Havlíček and *Lenochova* [50.41]	Red meat	Axilla	↑ Attractiveness, pleasantness, ↓ intensity	
Korman et al. [50.42]	*Hilbe* (fenugreek)	Skin, urine	Maple syrup	3-hydroxy-4,5-dimethyl-2(5H)-furanone (sotolone)
Lefèvre et al. [50.43]	Beer	Skin	↑ Attractiveness to malarial mosquitoes *(Anopheles gambiae)*	
Pelchat et al. [50.44]	Asparagus	Urine	Sulfurous, cooked cabbage	Methanethiol, carbon disulfide, dimethyl disulfide, dimethyl sulfide, dimethyl sulfone, dimethyl trisulfide, S-methyl-2-propenthioate
Suarez et al. [50.45]	Pinto beans, lactulose	Flatus	Rotten eggs, decomposing vegetables, sweet	Hydrogen sulfide, methanethiol, dimethyl sulfide, hydrogen sulfide
Suarez et al. [50.46]	Garlic	Breath	Garlic	Hydrogen sulfide, methanethiol, allyl mercaptan, allyl methyl sulfide, allyl methyl disulfide, allyl disulfide
Tamaki et al. [50.47]	Garlic	Breath	Garlic	Methanethiol, dimethyl sulfide, allylthiol, allyl methyl sulfide, dimethyl disulfide, methyl propyl sulfide, diallyl disulfide, 3-(allylthio) propionic acid
Yalcin et al. [50.48]	Fenugreek	Skin, urine	Maple syrup	3-hydroxy-4,5-dimethyl-2(5H)-furanone (sotolone)

a different diet, but their performance was not higher than chance when assessing odor of twins on the same diet [50.54]. This task appears to be too difficult even for trained dogs. They successfully discriminated between the odors of both dizygotic and monozygotic twins on different diets, but not the odors of monozygotic twins on the same diet [50.55].

Perhaps predictably, the main source of bodily odors that is affected by diet is breath odor. Breath malodor could have a profound impact on everyday social interactions [50.56] as numerous volatiles emanate from consumed food due to mastication and digestive processes in both the oral cavity and the stomach. Nevertheless, only some parts of the diet produce specific odor profiles. Garlic odor would be a representative ex-

ample. It has been demonstrated that the typical garlic odor in breath is more intense after ingestion of raw garlic compared to cooked garlic [50.47]. The characteristic odor consists of distinctive sulfur-containing compounds (allicin, mono-, di- and trisulfides, ajoene, and vinyldithiines). Moreover, this odor lasts for several hours even despite oral hygiene, especially due to the unique derivation of allyl methyl sulfide from the gut. Thus, *garlic breath* initially originates from the mouth and subsequently from the gut [50.46].

Another source of bodily odors originates from digestive processes. Action of bacteria on endogenous sources produces gases within the digestive system [50.57]. These eventually emerge as flatus that consists of both nonodorous compounds, such as oxygen,

Fig. 50.1 An odor sample rating session (courtesy of J. Fialová)

Fig. 50.2 Mean ratings ($\pm$ SE) of 16 pairs of axillary odors on pleasantness, attractiveness, and intensity in the experimental (*garlic*) condition (*gray bar*) and control (*non-garlic*) condition (*brown bars*) by 40 women. Ratings were on 7-point scale (e.g., 1 – very unpleasant and 7 – very pleasant). *Asterisks* indicate level of significance in paired *t*-tests. $^{*}p < 0.05$ level; $^{**}p < 0.01$ level (after *Fialová* et al. [50.39])

nitrogen, carbon dioxide, hydrogen and methane, and odorous ones containing sulfur, the production of which could be affected by dietary habits [50.45]. Higher levels of sulfur occur in some breads, dried fruits, brassicas and soy flour. A study where flatulence was increased in participants due to consumption of pinto beans and lactulose found that flatus malodor correlates with the concentration of hydrogen sulfide (reminiscent of rotten eggs) and methanethiol (decomposing vegetables) [50.58]. Similarly, urine of people who have recently eaten asparagus has an unusual sulfurous odor similar to cooked cabbage [50.44].

Several case studies show that the mother's diet might also affect the body odor of the newborn baby. For instance, in one case, a newborn baby had body odor and urine that smelled of maple syrup. The baby was therefore suspected of having maple syrup syndrome, but subsequent laboratory tests did not confirm this diagnosis. It was subsequently discovered that, prior to delivery, the mother ate fenugreek-spiced food which was responsible for this distinctive odor [50.42, 48]. The *maple syrup* odor that appears after fenugreek consumption was recently analyzed and several compounds which could be responsible for the distinctive odor were found in human sweat [50.59]. The same odor may also be detected exuding from the mother's skin and may be transmitted to the infant via the mother's breast milk [50.42]. In other cases, the mother consumed *shug* (a dish containing cumin, garlic, salt,
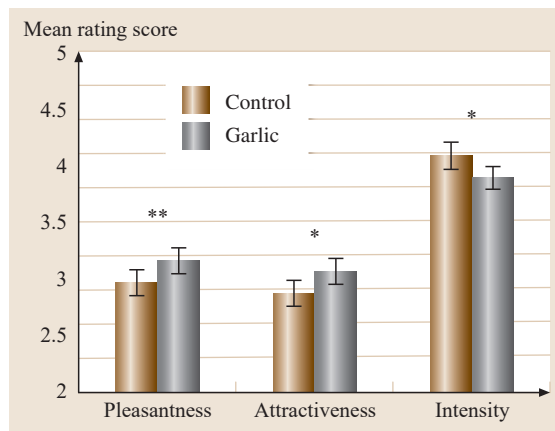
oil, and pepper) and her baby consequently smelled of cumin. In a similar way, a newborn baby and its amniotic fluid was found to be yellowish, with an odor reminiscent of curry, after the mother ate *amba*, which consists of mango, saffron, and curry [50.40].

The evidence on the effects of the diet on axillary odor is comparatively limited. One study [50.41] investigated whether consumption of red meat affects human body odor, because people from some predominantly vegetarian cultures say that people who eat meat smell bad because of it. The results of the study showed that the axillary odor of individuals on a nonmeat diet was perceived as more attractive, more pleasant, and less intense than the odor of the same individuals on a diet containing meat (at least one meat dish daily for 2 weeks). These results might appear counterintuitive, as meat consumption is thought to play a significant role in human evolution, and because they might be at odds with studies on effects of high protein diets in rodents (see above). The explanation may be that the amounts of meat consumed in contemporary populations, and in Havlicek and Lenochova's experiment, may be higher than would normally be experienced in traditional or ancestral societies. In this way, body odor changes after consumption of relatively large quantities of meat could in fact resemble a metabolic disorder [50.41]. Another surprising finding resulted from a series of studies that examined the effects of garlic consumption on axillary odor. Samples of body odor from the same individuals were obtained in both an experimental

(high garlic consumption) and control condition. Axillary odor of the participants after ingesting garlic was perceived as more attractive, more pleasant, and less intense (Fig. 50.1). In contrast to the effects of garlic on breath odor, the positive influence on axillary odor might be explained by longer term health benefits of garlic consumption, including antioxidant action and antibacterial activity [50.39] (Fig. 50.2).

Interestingly, dietary effects might also affect attractiveness of human body odor to blood sucking insects. *Lefèvre* et al. [50.43] found that beer consumption increases human odor attractiveness to malarial mosquitoes (*Anopheles gambiae*). Exposure to the body odor of participants who consumed beer caused an increase in mosquito activation (take-off and up-wind flight) and orientation (flying toward volunteers' odors).

50.5 Diseases and Disorders

The profile of volatile compounds found in human body odor can be affected by health and disease. This was recognized by ancient medical authorities, such as Hippocrates, Galen, and Ibn Sina, who advocated the use of olfaction in medical diagnostics. Recent technological advances and availability of highly sensitive techniques like gas chromatography-mass spectrometry (GC-MS) makes volatile compounds an increasingly significant part of early disease diagnostics. Generally, such changes in body odor might be either a result of altered metabolism and/or more direct effects of infectious agents. For this reason, metabolic disorders and infectious diseases are reviewed separately in the following paragraphs, where we present some representative examples of the effects of disease on body odor (Table 50.2).

50.5.1 Metabolic Disorders

The main cause of metabolic disorders is deficiency in enzymes or transport systems. Such deficiencies frequently lead to the accumulation of specific metabolites and in some disorders, to its further conversion to other compounds. If these are volatile, the metabolite or its products may lead to a characteristic odor profile in affected individuals. These metabolic disorders are often a consequence of simple Mendelian inheritance.

Isovaleric Acidemia
The disorder is caused by a deficiency of the isovaleryl-CoA dehydrogenase, which is involved in leucine metabolism. Due to the disorder, isovaleric acid accumulates in the tissues and leads to serious ketoacidosis which may subsequently result in coma [50.83]. Patients with isovaleric acidemia produce high levels of isovaleric acid in body fluids and urine, which is characterized by the distinctive odor of sweaty feet [50.64].

Maple Syrup Urine Disease
This is an autosomal recessive inherited disorder caused by deficiency in the enzyme 2-oxo acids dehydrogenase complex, which results in the accumulation of branched-chain amino acids, such as leucine in tissues and body fluids [50.84]. If not recognized early after birth and treated by a branched-chain amino-acid-free diet, the disorder can result in mental retardation. Body odor and urine odor of affected individuals smell relatively pleasant, resembling maple syrup. The compound responsible for the odor appears to be sotolone (3-hydroxy-4,5-dimethyl-2(5H)-furanone) [50.63].

Phenylketonuria
This disorder is caused by a recessive mutation in a gene coding for phenylalanine hydroxylase. The enzyme is expressed in liver tissue where it converts the amino acid phenylalanine into tyrosine. Due to the phenylalanine hydroxylase deficiency, the phenylalanine is converted to phenylpyruvic acid and phenylacetate which are excreted in sweat and urine. The phenylacetate gives affected individuals a musty odor, resembling sweaty lockers [50.61].

Trimethylaminuria
The disorder is characterized by a deficiency of the flavin containing monooxygenase 3 which converts trimethylamine to trimethylamine N-oxide. Trimethylamine is produced by gut bacteria from choline rich food, such as eggs or legumes. In unaffected individuals, most of the odorous trimethylamine is converted in hepatic tissue to odorless trimethylamine N-oxide. However, in people suffering from trimethylaminuria, trimethylamine emanates from their breath, sweat, and urine, with an odor which resembles that of decaying fish [50.60].

Diabetes
An example of a metabolic disorder with an etiology involving multigenetic as well as environmental factors (e.g., dietary habits) is diabetes. Type I diabetes is characterized by insufficient secretion of insulin, and the lack of insulin leads to an increase in the level of ketones including acetone in the blood. As a consequence, people suffering from diabetes with elevated

Table 50.2 Summary of studies on disease-related body odors

Authors	Disease/Disorder (Pathogenic agent)	Pathology/Symptoms	Odor source	Odor quality	Volatile compound(s)
Metabolic disorders					
Chalmers et al. [50.60]	Trimethylaminuria	↓ Flavin monooxygenase 3	Breath, sweat, urine	Decaying fish	Trimethylamine
Cone [50.61]	Phenylketonuria	↓ Phenylalanine hydroxylase	Sweat, urine	Musty, wolf-like, barny, sweaty locker-room towels	Phenylpyruvic acid
Laffel [50.62]	Diabetes	↓ Insulin secretion	Breath	Sweet	Ketones (acetone)
Podebrad et al. [50.63]	Maple syrup urine disease	↓ 2-oxo acids dehydrogenase	Skin, urine	Relatively pleasant, maple syrup like	3-Hydroxy-4,5-dimethyl-2(5*H*)-furanone (sotolone)
Tanaka et al. [50.64]	Isovaleric acidemia	↓ Isovaleryl-CoA dehydrogenase	Urine	Sweaty feet	↑ Isovaleric acid and its derivatives
Infectious diseases					
Anderson et al. [50.65] *Landers* et al. [50.66] *Wolrath* et al. [50.67]	Bacterial vaginosis (Gram-negative bacteria *Gardnerella vaginalis*, *Mycoplasma*)	Abnormal vaginal discharge (color, consistency, amount), itching, burning, dysuria	Vagina	Cheesy, fishy, foul	Trimethylamine
Finlay et al. [50.68]	Skin ulcers (*Bacteroides*, *Propionibacterium*)	Cutaneous lesions	Skin	Offensive, foul	
Garner et al. [50.69]	Cholera (*Vibrio cholera*)	Watery diarrhoea, vomiting, dehydration	Feces	Sweetish	Dimethyl disulfide, *p*-menth-1-en-8-ol
Honig et al. [50.70]	Scarlet fever (*Streptococcus pyogenes*)	Red-colored rash on the body, sore throat and fever	Skin, breath	Foul	
Liddell [50.71]	Typhoid fever (*Salmonella typhii*)	High fever, drenching sweat, gastroenteritis	Skin	Baked brown bread	

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Table 50.2 (continued)

Authors	Disease/Disorder (Pathogenic agent)	Pathology/Symptoms	Odor source	Odor quality	Volatile compound(s)
Phillips et al. [50.72], *Syhre and Chambers* [50.73] *Syhre* et al. [50.74]	Tuberculosis (*Mycobacterium tuberculosis*)	Cough, chess pain, weight loss, fever, night sweats	Breath	Foul	Methyl nicotinate, methyl phenylacetate, methyl *p*-anisate, *o*-phenylanisole, cyclohexane, benzene derivatives, decane, heptane
Shirasu and Touhara [50.75]	Diphtheria (*Corynebacterium diphtheriae*)	Sore throat, fever, difficulty breathing	Breath	Sweetish, putrid	
Tumors					
Jobu et al. [50.76]	Bladder		Urine		Ethylbenzene, nonanoyl chloride, dodecanal, (*Z*)-2-nonenal, 5-dimethyl-3(2*H*)-isoxazolone
Phillips et al. [50.77]	Lung		Breath		Alkanes, alkane and benzene derivatives, isoprene, benzene
Phillips et al. [50.78]	Breast		Breath		2-propanol, 2,3-dihydro-1-phenyl-4(1*H*)-quinazolinone, 1-phenyl-ethanone, heptanal, isopropyl myristate
Psychiatric disorders					
DiNatale et al. [50.79] *Phillips* et al. [50.80] *Phillips* et al. [50.81], *Smith* et al. [50.82]	Schizophrenia	Hallucinations, delusions, cognitive deficit	Breath	Peculiar, unpleasant	*Trans*-3-methyl-2-hexenoic acid, carbon disulfide, pentane

ketones produce acetone from their breath, which gives off a characteristic sweet smell [50.62].

50.5.2 Infectious Diseases

The pathogenic activity of many infectious agents also produces various volatile compounds which are emitted from skin, breath, sweat, vaginal fluid, urine, and feces. In contrast to odor-producing metabolic disorders, which are frequently characterized by specific volatile molecules with distinctive odor as we have just described, effects on odor of patients with infectious diseases are more complex and therefore more challenging to characterise. This can be attributed to three main reasons:

1. Bacteria of one strain/species may metabolize different substrates producing a complex mixture of volatiles.
2. Different bacteria overlap in the specific volatiles they produce.
3. Some diseases are frequently characterized by multiple infections which may lead to less characteristic odor.

Several infections of the digestive system are characterized by distinctive fecal odor. This involves infection by *Vibrio cholerae* which causes acute watery diarrhoea with a distinctive sweetish odor. The volatile compounds responsible for the odor were identified as p-meth-1-en-8-ol and dimethyl disulfide [50.69].

Infections of the respiratory system frequently affect breath odor. For instance, people suffering from lung tuberculosis, caused by infection with *Mycobacterium tuberculosis*, are reported to have foul breath odor. A specific mixture of volatile compounds was reported from the breath of infected patients, with a similar volatile profile found in in vitro cultures [50.73]. The biomarkers of tuberculosis infection were proposed to be nicotinic acid, cyclohexane and some benzene derivatives [50.72, 74]. Similarly, individuals infected with *Corynebacterium diphtheriae* are characterized by sweetish and putrid breath odor, resulting from effects of the diphtheria-causing bacteria on the upper respiratory system, generating other symptoms including sore throat and swollen tonsils [50.75].

The vagina is a major source of body odor in adult women. It is rich in residential microflora which play a part in odor production. Changes in vaginal odor might reflect infection by pathological agents and it is frequently used by gynecologists in differential diagnostics [50.65]. For instance, bacterial vaginosis is frequently accompanied by a cheesy or fishy odor which is caused by the production of highly odorous trimethy-

lamine [50.67]. Women diagnosed for an infection by the protist *Trichomonas vaginalis* also frequently complain about malodor [50.66].

Perhaps most common are changes in skin odor caused by infections. These may derive from infection in other parts of the body, such as infection of the intestinal tract by *Salmonella typhi*, the agent of typhoid fever. People suffering from typhoid fever are said to smell like baked bread [50.71]. Infections directly affecting the skin include scarlet fever caused by *Streptococcus pyogenes*. The disease manifests in the form of a rash, strawberry-colored tongue, and fever, but patients also emit a distinctive foul odor from their skin and breath [50.70]. An offensive smell is also associated with anaerobic infections (e.g., by *Bacteroides*, *Propionibacterium*) which cause skin ulcers. Patients often complain about the strong smell which can be significantly reduced by cutaneous application of metranidazol [50.68].

50.5.3 Tumors

Oncological disorders are characterized by abnormal cell growth, mostly caused by mutations in genes (or epigenetic factors) controlling for cellular growth and division. However, neoplasia might be caused by various genes and further development depends on affected tissue. Nevertheless, affected cells might show specific metabolic changes, partly attributable to oxidative stress, and production of distinctive patterns of volatile molecules. Recently, there has been increased interest in the analysis of various substances in patients with different carcinomas. Air exhaled by individuals with lung cancer form a specific pattern of volatile molecules including alkanes, alkane derivatives, and benzene derivatives [50.77]. Similarly, people diagnosed with breast cancer emanate a specific profile of volatiles in their breath. Five biomarkers for breast cancer have been detected including 2-propanol, heptanal, and isopropyl myristate [50.78]. In addition, the urine of people suffering from bladder cancer and prostate cancer has been analyzed. Volatile metabolites reported to be related to bladder cancer include dodecanal, 2-nonenal, and ethylbenzene [50.76]. The specific odor profile associated with several carcinomas has been confirmed by studies using dogs as cancer detectors. Dogs can be trained to differentiate between breath or urine odor samples taken from people suffering from lung, bladder, and prostate cancer [50.85].

50.5.4 Psychiatric Disorders

For a long time, it has been noted by psychiatric hospital personnel that certain psychiatric conditions can be as-

sociated with a peculiar odor. Schizophrenia, in particular, has attracted most attention. Early studies claimed to identify *trans*-3-methyl-2-hexenoic acid as a reliable marker of schizophrenia-associated odor [50.82]. These results were subsequently questioned [50.86], but a further study found that schizophrenic patients may indeed show elevated levels of this compound [50.79]. More recently, analysis of breath volatiles indicates that compounds like carbon disulfide, pentane, and several other volatiles might be associated with schizophrenia [50.80, 81]. Interestingly, other patients treated with neurolep-

tics did not share the same pattern of volatiles. This suggests that compounds associated with schizophrenia are not a by-product of the medical treatment, although further studies are needed.

There is accumulating evidence showing that some affective states, such as anxiety, influence axillary body odor (for review see [50.11]). One may therefore speculate whether some affective disorders (e.g., major depression) are also associated with changes in the body odor. To our knowledge, there has not yet been a systematic investigation on this subject.

50.6 Conclusion

Seen from various perspectives, human body odor is a highly complex biological system. First, it consists of several sources, such as the axillae, skin, mouth, feet, anogenital region, and the scalp. Each of these sources is characterized by sets of dozens or even hundreds of different volatile compounds. Second, most of the volatile compounds are not directly produced by the human body, but mainly result either from residential or pathogenic bacterial metabolic activity. Third, each human is characterized by an individual odor profile, which is partly due to the genetic influences. This profile is relatively stable across the life span and contributes to individual olfactory identity and may affect social interactions. On the other hand, individual body odor can also be altered by various intrinsic and extrinsic factors.

The main aim of this chapter was to review selected factors contributing to the inter- and intraindividual variation in body odor. We first focused on differences in body odor associated with between-individual differences in personality and sexual orientation (other sources of variation include factors, such as genotype at the major histocompatibility complex (Chap. 49). We then described within-individual changes in body odor due to hormonal influences, in which odor seems to be intimately associated with hormonal fluctuations, although it must be said that most research has focused on steroid hormones, such as estrogens or testosterone. It is noteworthy that other humans can perceive hormone-related changes in body odor and that odor might therefore provide important social cues, perhaps especially those relevant to reproduction, such as actual or potential fertility. Nevertheless, most of the chemicals

responsible for hormone-related effects are currently not identified and await further investigation.

One of the major influences on body odor quality is considered to be diet, which contains numerous aromatic chemicals of mainly plant origin. As expected, various volatiles consumed in the diet affect breath and fecal odor. However, some compounds might also be emitted from the skin surface, or can influence body odor indirectly via several possible mechanisms, including oxidative metabolism, nutritional status, and antibacterial action. The effect of diet might also show an idiosyncratic pattern as a result of the interaction between digested food and individual genetic make-up. Unfortunately, these interactions are currently poorly understood.

Finally, various disorders and diseases are characterized by specific odors which are often used in clinical diagnostics or may be at least increasingly utilized in the future as a diagnostic mean. This is pronounced in the case of inherited metabolic disorders which often results in the production of unusual volatiles or their metabolites. Several carcinomas, such as lung or bladder cancer, are also known to be associated with changes in produced volatiles, and these can be used in early screening. More complex odor profiles are associated with some infectious diseases. The potential for using these changes in screening looks likely to increase in the near future.

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