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Skin volatile organic compound emissions from 14 healthy young adults under controlled conditions

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Highlights

- VOC species and emission rates of whole-body skin from 14 subjects were determined.
- Eight VOCs (skin ozonolysis products) were emitted from the skin of all subjects.

- VOC emission rates were significantly different among the subjects.

Abstract

The human skin is an important source of volatile organic compounds (VOCs) in indoor environments. In this study, VOC emissions from whole-body skin of 14 healthy young adults were measured using a specially designed environmental chamber under controlled conditions. The number of VOC species in whole-body skin emissions ranged from 38 to 69 and the total emission rate of all VOCs detected in whole-body skin emissions ranged from 164 to 518 μg/h. The similarities of VOC species among different subjects were more prominent, while the emission rate of the same VOC among different subjects varied significantly. In particular, eight VOCs (acetone, 6-methyl-5-hepten-2-one (6-MHO), geranylacetone, hexanal, heptanal, octanal, nonanal, and decanal) were emitted from the skin of all subjects, most likely originating due to the reaction of ozone with human skin. These VOCs accounted for a relatively large proportion of the total emission rate, indicating that the reaction of skin with ozone was an important source for skin VOC emissions. In addition, siloxanes, aldehydes, ketones, and alcohols contributed remarkably to whole-body skin emission rates. Overall, this study showed information on the apportionments of VOC species and emission rates of whole-body skin emissions, which shed more light on the emission characteristics of human skin as a VOC source.

Introduction

In recent years, volatile organic compound (VOC) pollution in densely occupied environments has attracted significant attention [[1], [2], [3]]. Studies have shown that the human body is an important source of VOC emissions in indoor environments [[4], [5], [6], [7], [8]]. Therefore, it is important to explore the characteristics of human VOC emissions. The human body emits VOCs through its breath and skin via different mechanisms [9,10]. Numerous quantitative and qualitative research have focused more on breath emissions than skin emissions [[11], [12], [13], [14], [15]].

Previous studies on skin VOC emissions mainly provided species information. Researchers have reported 532 VOCs in human skin secretions [16], of which only 20–90 VOCs were thought to be naturally released from the skin surface at body temperature [10]. These studies used contact sampling or headspace sampling of specific local skin from different body parts, such as axillae, hands, and feet to obtain information on the emitted VOC species. Zeng et al. found that straight-chain, branched, and unsaturated acids from C6 to C11, especially (E)-3-methyl-2-hexenoic acid, were important sources of axillary odors [17,18]. Curran et al. detected organic fatty acids, ketones, aldehydes, esters, and alcohols in axillary sweat samples [19]. Penn et al. found 373 peaks in axillary sweat samples, of which only 38 were common to more than half of the samples, suggesting significant differences among people [20]. Zhang et al. identified 35 VOCs, including alkenes, alkanes, alcohols, aldehydes, and esters in the headspace samples of hands and forearms [21]. Mochalski et al. detected 64 VOCs from C4 to C10 in the skin emanations of hands and forearms, which were dominated by aldehydes, hydrocarbons, and ketones [22]. Dormont et al. identified 44 VOCs in human feet, with the highest concentrations being those of nonanal and decanal [23]. Caroprese et al. found nine fatty acids in the headspace samples of feet, with acetic, butyric, isobutyric, and isovaleric acids being identified as the main causes of foot odor [24]. In these studies, the VOC profiles of different body part emissions varied due to the uneven distribution of glands and microorganisms on the skin surface. The results of local skin emissions do not represent the characteristics of whole-body skin emissions. Therefore, some studies have attempted to obtain VOC species information of entire skin emissions. Logan et al. [25] and Harraca et al. [26] identified 24 VOCs and five VOCs emitted from the whole body except the head, respectively, to explore the biomarkers of insect attraction in humans; however, these results were qualitative. These studies provided substantial results for understanding the species distribution of VOCs emitted from the skin and also revealed that human skin is a complex VOC source. However, they were insufficient to reflect the emission characteristics of whole-body skin.

Few studies have analyzed the effects of factors, such as age, gender, ozone concentration, and temperature on skin emissions by focusing on changes in the abundance of target VOCs. Haze et al. reported that 2-nonenal was detected only in shirts that were worn for three days by older subjects, but not in the shirts of younger subjects [27]. Gallagher et al. found that dimethylsulphone, benzothiazole, and nonanal were more abundant in emanations from the backs and forearms of older subjects than those of younger subjects, while hexyl salicylate and a-hexyl cinnamaldehyde were less abundant. Moreover, no significant sex-related differences were observed in their study [28]. Some studies tested whole-body emissions rather than local skin emissions by placing several human subjects in an environmental chamber and comparing VOC concentrations under different conditions. Bekö et al. showed that the steady-state concentrations of acetone, geranylacetone, 6-methyl-5-hepten-2-one (6-MHO), and 4-oxopentanal (4-OPA) in an environmental chamber were significantly different in the presence and absence of ozone [29]. Weschler et al. reported that the addition of ozone to the cabin resulted in a remarkable increase in the abundance of saturated aldehydes from C4 to C10, which were the major components of VOCs in the cabin when ozone was present [30]. Wisthaler et al. obtained the primary and secondary products of the reaction of skin with ozone, according to the variations in the VOC concentrations when ozone was added [31]. Tsushima et al. compared the concentrations of VOCs contributed only by whole-body skin emissions with and without ozone at 23 °C and 28 °C, and found that when the temperature was increased to 28 °C, there was a rise in the concentrations of squalene and other high molecular weight compounds. In contrast, when ozone was removed from the air supply, concentrations of nonanal, decanal, geranylacetone, and 6-MHO were found to decrease [32]. These studies identified certain markers that could characterize age characteristics or skin reactions with ozone by comparing the abundances or concentrations of specific VOCs. However, the comprehensive and quantitative characteristics of skin VOC emissions were lacking.

Source intensity characteristics, which are the most basic quantitative characteristics of pollution sources, have rarely been reported. Tang et al. [7], Stönner et al. [33] and Arata et al. [34] monitored VOC concentrations in university classrooms, screening rooms of a cinema, and residences, respectively, and calculated the average VOC emission rates of each person in field environments. However, the average value did not reflect the emission characteristics of each individual, owing to individual differences. He et al. presented the VOC emission rates of each subject's entire body by measuring the changes in VOC concentrations caused by a single subject in an environmental chamber [35]. Additionally, they attempted to obtain the skin emission rate by subtracting the breath emission rate from the whole-body emission rate. However, subtraction exacerbated the uncertainty of the results due to experimental errors. Mochalski et al. obtained the emission rates of 12 volatiles emitted from whole-body skin by separating the exhalation from the chamber air [36]. However, the experiments were not conducted under controlled environmental conditions, making the emission rate results difficult to compare or repeat. Zou et al. presented an experimental method for separately measuring the whole-body skin emissions of an individual under controlled conditions and reported the whole-body skin emission rates of one subject [37]. Overall, the results of whole-body skin emission rates were still lacking.

The objective of this study was to present the VOC emission profiles of whole-body skin, including VOC species and emission rates in order to provide further information on the emission characteristics of human skin as a source of VOCs.

Section snippets

Materials and methods

An experimental method for separately measuring whole-body skin emissions of an individual person under controlled conditions was proposed and validated in the previous study [37]. In this study, all human subjects were tested one by one using this experimental method under controlled conditions. Whole-body skin VOC emissions from each subject were analyzed to obtain a comprehensive VOC profile of skin emissions, including the apportionments of VOC species and emission rates.…

Species distribution of VOCs emitted from whole-body skin

A total of 143 VOCs were detected in the whole-body skin emissions of 14 subjects under the "basic condition," including aromatics, esters, siloxanes, alcohols, alkanes, aldehydes, ketones, alkenes, nitrides, halides, acids, etc. Table 2 shows the chemical classification of these compounds. Among them, aromatic compounds were the most abundant, followed by esters, siloxanes, alcohols, and alkanes. Fig. 3 presents the distribution of the detection rates of 143 VOCs in the whole-body skin…

Conclusions

In this study, VOCs emitted from whole-body skin of 14 healthy young adults were measured. "Basic condition" was defined to reduce the interference of various factors on skin emissions by controlling the environmental parameters and subjects' state. All experiments were performed under "basic condition" to obtain VOC profiles of whole-body skin emissions of the 14 subjects.

The number of VOC species in whole-body skin emissions ranged from 38 to 69 in the 14 subjects. The commonality of VOC…

CRediT authorship contribution statement

Ziwei Zou: Writing – original draft, Methodology, Investigation, Data curation. **Xudong Yang:** Supervision.…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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