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One health: the impact of environment, detergents and hygiene on barrier, microbiome and allergy

Hanna Mayerhofer · Isabella Pali-Schöll

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Summary A variety of body surfaces, such as skin and mucosal membranes—from the nasopharyngeal area to the lungs, uterus, vaginal area, and digestive tract—contain complex microbial ecosystems that are tailored to the specifics of the respective niche [1].
The so-called dysbiosis—a disadvantageous change in the composition of the microbiome—is associated with the pathogenesis of a variety of diseases [2]. Gastrointestinal as well as cardiovascular, metabolic, neurodegenerative, psychological, oncological, and also allergic diseases have been linked to microbial dysbiosis. Susceptibility to allergies can be due to genetic predisposition; in addition, extrinsic factors from today's lifestyle increasingly contribute to microbiome changes, but also to the disruption of the skin and mucosal barrier and thus to the development of allergies [3].
Gisela, a fictional farmer, guides us through this review. She is representative of adults and children of all genders in industrialized countries. During her daily routine, the skin and mucosal microbiome is influenced by a variety of exogenous factors. These include everyday personal hygiene products, detergents for laundry and dishes, food, medication, animal contact, and exposure to various outdoor environments. Gisela's daily routine will illustrate how the human microbiome and the skin barrier are modified in positive or negative ways, and how this could influence the development of allergies. Furthermore, potential measures for the prevention and management of dysbiosis will be discussed in terms of examples of alternative products and behaviors.

Keywords Allergy · Barrier · Gut–skin axis · Skin barrier · Microbiome · One health

Abbreviations

AD	Atopic dermatitis
AHR	Aryl-hydrocarbon receptor
AR	Allergic rhinitis
ASV	Amplicon sequence variant
BLG	Beta-lactoglobulin
ClfB	Surface protein clumping factor B
FOS	Fructo-oligosaccharide
GOS	Galacto-oligosaccharide
GPR	G-protein-coupled receptor
HDAC	Histone deacetylase
NBS	Nature-based solutions
NMF	Natural moisturizing factor
PBMC	Peripheral blood mononuclear cell
PFA	Polyunsaturated fatty acid
PPI	Proton pump inhibitor
S. aureus	*Staphylococcus aureus*
SCFA	Short-chain fatty acid
SDBS	Sodium dodecylbenzene sulfonate
SLS/SDS	Sodium lauryl sulfate/sodium dodecyl sulfate
Syndet	Synthetic detergent

H. Mayerhofer · Dr. I. Pali-Schöll, PhD (✉)
Department for Interdisciplinary Life Sciences, University of Veterinary Medicine Vienna, Medical University Vienna and University Vienna, Vienna, Austria
isabella.pali@vetmeduni.ac.at

H. Mayerhofer · Dr. I. Pali-Schöll, PhD
Institute of Pathophysiology and Allergy Research, Centre of Physiology, Pathophysiology and Immunology, Medical University Vienna, Vienna, Austria

H. Mayerhofer
AllergyCare, Allergy Diagnosis Center, Private Clinic Döbling, Vienna, Austria

Personal hygiene: from toothpaste to soap

Scene 1: *Gisela gets up in the morning, stumbles into the bathroom, washes her hands with olive oil soap and her face with water, and brushes her teeth.*

Like most toothpastes, hers contains sodium lauryl sulfate (SLS; also known as sodium dodecyl sulfate, SDS), an anionic surfactant that acts as a detergent (as discussed later for detergents, cleaning agents, and hygiene products) and is also responsible for foam-building. In addition, SLS reduces plaque and bad breath [4]. However, due to its protein-denaturing properties, it can lead to undesirable side effects, among which are allergies. Furthermore, SLS might also be toxic to the cells of the oral mucosa: Four people were tested in a study, where they used toothpaste "with fluoride/with SLS" or "with fluoride/without SLS" or "without fluoride/without SLS" for 2 months [5]. Significant cellular changes were found, including more frequent occurrence of pyknotic cells, i.e., condensed and knotted chromosomes in the nucleus; cells with karyorrhexis, i.e., fragmented chromatin; and nuclear nodules when SLS-containing toothpaste was used for 60 days. These nuclear morphological changes in the buccal epithelial cells due to SLS may also impact the barrier function. The fluoride content of the toothpaste did not influence these parameters. As shown in a mouse model, swallowing SLS-containing liquids—including toothpaste—could be associated with the development of eosinophilic esophagitis, a chronic allergic disease of the esophagus [6].

Washing agent

Scene 2: *Refreshed and alert, Gisela puts on her everyday clothes.*

Microbiome- and therefore allergy-influencing substances can also be found on clothing and laundry. Sodium dodecylbenzene sulfonate (SDBS), a surfactant similar to SLS, is a key ingredient in detergents and is responsible for pore formation, anti-adhesion, wetting, and solubilization and thus for a large part of the cleaning power. It additionally has properties for foam formation, dispersion, reduction of viscosity, and emulsification/de-emulsification [7]. A study showed that residues of detergents such as SDBS and proteases from detergents are present in high concentrations after washing and drying clothes and retain their toxic and barrier-destroying effects even after the wash cycle [8]. Toxic effects were observed when human keratinocytes were stimulated with laundry detergents [9]. Considering the close contact with human organs, the irritating and sensitizing ingredients of detergents can easily be inhaled even from freshly washed clothes and enter the lungs. In addition, many detergents and cosmetics also contain the enzyme papain, which is structurally and functionally similar to the house dust mite allergen Der p 1 [10]. Studies by our group with animal models have shown that both papain and Der p 1 increase the transepidermal water loss of the skin barrier and promote allergic inflammation [11, 12].

Nutrition

Scene 3: *The busy morning in the barn has made Gisela hungry. Unfortunately, she does not have much time to prepare food today, so she simply puts frozen chips and fish sticks in the oven. The fast meal is accompanied by ketchup and mayonnaise and a glass of lemonade. For a quick dessert she eats a chocolate bar.*

Diet plays a major role in the composition of our gut microbiome [13, 14]. It has been shown to be particularly beneficial if the diet is rich in fiber and thus provides the intestinal microbes with high-quality nutrients (prebiotics). These polysaccharides and oligosaccharides, such as galacto-oligosaccharides (GOS), fructo-oligosaccharides (FOS), and inulin, are fermented into short-chain fatty acids (SCFA) such as butyrate, propionate, acetate, and lactate by intestinal bacteria such as bifidobacteria, which have the appropriate enzymes. These SCFA not only serve as food for the beneficial microbes *per se*, but they also provide energy to the intestinal cells and acidify the intestinal contents, suppressing the growth of pathogenic germs. Equally important is the signaling effect of SCFA: They bind "metabolite-sensing" G-protein-coupled receptors (GPR) such as GPR43, GPR41, and GPR109, which are involved in the rapid establishment of intestinal homeostasis and immune response. Consequently, the development of regulatory T cells, epithelial integrity, dendritic cell biology, and IgA responses are affected. In addition, via epigenetic modifications, such metabolites can also have long-term effects as they can inhibit histone deacetylases (HDAC) or activate transcription factors like the aryl-hydrocarbon receptor (AHR; review article [13]).

Fermented foods such as sauerkraut and other fermented vegetables, kombucha, yoghurt, bread drinks, kefir, miso, tempeh, or kimchi are also beneficial as they directly provide microbes and their components, thus acting as probiotics [15, 16]. They increase microbiome diversity and reduce inflammatory markers [15]. One study showed that during a 10-week diet rich in fermented foods, all changes (16S amplicon sequence variants, ASV) occurred within the Firmicutes strain, including the *Lachnospiraceae* family, the *Ruminococcaceae* family, and the *Streptococcaceae* family [15]. Interestingly, the added microbes themselves did not multiply, but they changed the microbiome composition via other signaling pathways and molecules. Similarly, foods with vitamin A and especially omega-3 fatty acids (the latter in fish oil, algae oil, linseed oil) have a direct anti-inflammatory effect via various mechanisms and therefore counteract allergies: Essential long-chain polyunsaturated fatty acids (PUFA; omega-6, omega-3) and their metabolites are involved in the production of pro-inflammatory (omega-6, *n*-6) or anti-inflammatory (omega-3, *n*-3) prostaglandins and limit the infiltration of neutrophils [17]. Since *n*-6 and *n*-3 fatty acids compete for the same enzymes for elongation and desaturation, their ratio is crucial and should be low (*n*-6:*n*-3) for an anti-inflammatory effect.

The entire positive combination of the beneficial foods discussed above can be found, for example, in a Mediterranean diet [18] but also in the Nordic, Atlantic, or Japanese diets, which have a high proportion of vegetables, fruits, pulses, whole grains, and fish [17]. These ingredients provide a high ratio of *n*-3:*n*-6 fatty acids and a lower proportion of saturated fatty acids, and they counteract inflammatory as well as allergic diseases.

Dish detergent

Scene 4: *Gisela portions her lunch onto a fresh plate from the dishwasher.*

A research group investigated the effect of detergent and rinse aid residues, which remain on the surface after the dishes have been washed and dried, on the gastrointestinal epithelium [19]. One critical finding was that the alcohol ethoxylates contained in rinse aids remain on the dishes even after the dishes have been washed, and they retain their toxicity. Alcohol ethoxylates belong to the group of non-ionic surfactants and are effective as wetting and spreading agents and also as emulsifiers and foaming agents [20]. In addition to alcohol ethoxylates, conventional dishwashing detergents contain bleaching agents, enzymes, SLS, perfume, and many other chemicals which, even when highly diluted (1:20,000), promote increased cell death, cell migration, and inflammatory reactions in intestinal epithelial cells [19].

As the epithelial barrier hypothesis states, factors that damage the epithelial barrier lead to a vicious cycle characterized by epithelitis, migration of the microbiota into the subepithelial space, and dysbiosis [21, 22]. The severity of the damage depends on the type of substance, the duration and dose of exposure, and the type of tissue affected. Migration of the microbiome into subepithelial areas triggers a defense reaction against those newly colonizing facultative pathogens, usually mediated by a type 2 inflammatory reaction, which in turn further intensifies the inflammation. This is usually accompanied by immunoglobulin E (IgE) formation against the most important colonizing opportunistic pathogen, *Staphylococcus aureus* (*S. aureus*).

In addition, alarmins (interleukin [IL]-25, IL-33, thymic stromal lymphopoietin [TSLP]), which are central regulators of allergy pathology, are increased during the penetration of such pathogens into deeper skin layers [23].

Disinfectants

Scene 5: *Gisela reads the news: A coronavirus pandemic is keeping the country on tenterhooks. She is not affected by the lockdown; her farm is far from the next village and she is currently not meeting other people. However, she believes it is important to thoroughly disinfect her hands and surfaces as well as keep her work facilities clean to prevent spreading of the virus to her family or her animals.*

The COVID-19 pandemic led to a strong focus on personal hygiene with excessive and frequent use of hand sanitizers and various household detergents. In particular, the use of triclosan as an antibacterial substance in such products increased exponentially [24]. In bactericidal concentrations, triclosan is very effective against a broad spectrum of microorganisms, including antibiotic-resistant bacteria [25]. The chemical is absorbed through the skin and exerts a profound influence also on the gut microbiome, causing disturbances in both composition and function. A probiotic diet, especially with *Lactobacillus*, could counteract this toxic effect of triclosan and support the restoration of a beneficial gut microbiome [26]. In addition, numerous epidemiological studies report a link between triclosan exposure and allergic rhinitis (AR), asthma, and food sensitization [27]. Consistent with this, in a study of more than 4000 nurses, the use of various disinfectants was associated with poor asthma control [28].

Medication: antibiotics

Scene 6: *Gisela has been suffering from a sore throat for some time, so she takes her antibiotics for the day.*

In a meta-analysis, the use of antibiotics within the first 2 years of life was associated with long-term development of atopic dermatitis (AD), food allergies, general allergic symptoms, and asthma [29]. In the analyzed cohort, 70% of participants received antibiotics in the second year of life. Furthermore, the use of antibiotics with a broad spectrum of activity, such as cephalosporins and macrolides, increased the risk of long-term health problems.

One of the most likely mechanisms underlying this connection is the change in the microbiota. In addition to their often life-saving functions in combating bacterial diseases, antibiotics are known to cause profound changes in the microbiome, including a decline in bacterial diversity, changes in the abundance of certain bacteria, and an increase in antibiotic resistance [30]. Disruption of the intestinal microbiome early in life, when the microbiome and immune response develop simultaneously, is associated with the development of immune- and non-immune-mediated diseases [31]. Even temporary dysbiosis during this critical "window of time" can impair immune tolerance and proper immune responses.

Medication: gastric acid inhibitors

Scene 7: *Gisela's morning was stressful, first she didn't have time for breakfast, then the negative news about the pandemic, and she had to scarf down lunch because work was already calling—the manure must be loaded and driven away. There is no time for a break. After loading a few shovels, her stomach hurts and she starts to feel heartburn. Fortunately, she always has some acid-suppressing drugs at hand, whether prescribed by a doctor or bought over the counter.*

Gastric acid-suppressing medications such as proton pump inhibitors (PPIs), antacids, H2 receptor blockers, and alkaline powders are important for protecting the gastric mucosa from excess acid and are used for gastric diseases, such as gastritis, ventricular and duodenal ulcers, reflux disease, or Zollinger–Ellison syndrome, and for gastric protection during long-term therapy with nonsteroidal anti-inflammatory drugs. However, these acid-suppressing medications lead to an increased risk of allergies [32–35]. Our group showed that particularly the risk for food allergies in humans increases by 10–15% [34, 36]. Not only is there an increased likelihood of developing food allergy, but also an increased risk for allergic and even anaphylactic reactions at even low allergen concentrations [37]. The analysis of a large health dataset of people in Austria revealed the practical medical manifestation of this connection: After 7 years of first prescription of gastric acid suppression, significantly fewer people managed without anti-allergy medication than after taking other medications, such as antihypertensives or lipid-lowering drugs [38]. An animal model showed that IgE induction and thus allergy development is not only associated with inadequate degradation by digestive enzymes at elevated pH in the stomach [37], but is also related to a change in the gut microbiome [39]. Dysbiosis in the gut is especially promoted by gastric acid-inhibiting drugs such as PPIs, which represent one of the strongest classes of anti-acid medication [40]. In addition, the disturbed gut microbiome could also trigger dysbiosis on the skin via the gut–skin axis [13]. The risk of inducing allergies other than food allergies is therefore increased.

Contact with pets

Scene 8: *Gisela steps out into the courtyard, where she plays with her dog, cuddling and stroking him. The cat also joins for a cuddle.*

Contact with various pets and farm animals is a known factor that reduces the risk of developing allergic diseases [41]. For this benefit, (a) the time window in which the contact takes place and (b) the dose seems to be decisive: Especially in the first year of life, living together with many different species has a lasting allergy-preventive effect.

Exposure to dogs and cats during fetal development and in early infancy has a particularly positive effect on allergy prevention, including food allergies [42]. The close physical contact between animal and owner results in a lively exchange of the skin microbiome, which increases the diversity of the microbiota [43]. This has even been shown in a study with hand-raised wolves in parallel with dogs and their owners and caretakers [44].

The analysis of 168 dog-owner pairs revealed that inhalant allergies manifest similarly and often simultaneously in both the dogs and their owners [43]. At the same time, a higher allergy risk was found in dog-owner couples living in cities. This suggests that humans and dogs may be predisposed to allergies due to the same external risk factors.

In addition to the composition of the microbiome in the body, the microbiome in the household also plays an important role for the risk of allergies. A cohort study in Finland and Germany reported that dog ownership modifies the microbiome in the floor dust of living spaces: The bacterial and fungal microbiota was significantly higher and more diverse compared with homes where no dog was kept [45]. The increased diversity was due to dogs introducing their own microbiome as well as that from the environment into households. Prenatal and early childhood exposure to dogs was also associated with an altered gut microbiome during infancy, supporting a possible mechanism to explain a reduced risk of atopy and asthma [46].

Contact with farm dust and consumption of raw milk

Scene 9: *Gisela's farm specializes in livestock farming with numerous milk-producing cows. Gisela works in the barn every day and enjoys drinking a glass of chilled raw milk from her animals.*

If children are born and grow up on a farm or if the mothers spend time on a farm during pregnancy, these children have a significantly lower risk of asthma, atopy, and allergies. This phenomenon is based on the hygiene hypothesis [47]. It states, in several variations, that contact with germs in infancy and early childhood protects against asthma and allergies, and that, conversely, the increased hygiene of modern times reduces the antigen load and thus increases the risk of allergies [48].

In addition to contact with beneficial germs and their components, our research group showed that the milk protein beta-lactoglobulin (BLG) plays an important role in the preventive farm effect: It is a carrier protein with immunomodulatory effects. When loaded with its binding partners such as iron-siderophores [49–52], vitamin A [53] or D [54], or zinc [55], it can prevent an immune response or generally divert from an allergic immune status, which has been shown both in animal models and human studies with allergic patients [52, 56]. However, this milk protein is not only found in milk: We detected it loaded with zinc in stable dust, in ambient air around stables, and also in the households of cattle farms [55]. In cell stimulation studies of peripheral blood mononuclear cells from healthy donors, it was clear that BLG with zinc counteracted a Th2 cytokine response, whereas unloaded BLG tended to favor a Th2 milieu. In the animal model, intranasally administered stable dust with BLG showed a much better allergy-preventive effect than dust specifically depleted of BLG [55].

The consumption of raw milk also showed a protective effect independent of farm life [57]. Several heat-sensitive proteins from the whey fraction were held responsible for this effect [58]. Beta-lactoglobulin also belongs to this fraction and is being investigated in ongoing studies for its mode of action in raw milk (Pali-Schöll, unpublished data).

Similarly structured carrier proteins showed comparable effects in our recent studies: The *Alternaria alternata* mold allergen associated with the ligand vitamin A reduced allergy symptoms in animal models [59].

Contact with nature and soil, and spending time in biodiverse green spaces

Scene 10: *Gardening is next on Gisela's to-do list: In the kitchen garden the weeds must be plucked, the raspberries need to be picked, fallen fruit should be collected for juicing; she also quickly cuts the natural meadow around the trees with a sickle. Gisela likes to do all this work without gloves, allowing her a better grip. After the back-straining work, she calls her dog for a walk through the nearby meadows and woods.*

Spending time in biodiverse green areas, i.e., areas with as many different plants as possible and contact with green natural areas and soils, proved to be beneficial (biodiversity hypothesis; [60, 61]). Time in nature is even being discussed as an approach for the prevention and management of various diseases (nature-based solutions [NBS]; [62–64]). These contacts enrich the human microbiome, increase immune balance, and build up protection against allergies and inflammatory diseases. However, it was shown that the type of green space is decisive, e.g., conifer forests in the environment were rather unfavorable in the first 2 years of life of Finnish children born in spring, increasing the risk of eczema (adjusted odds ratio: 1.19; [65]). However, a reduced risk of AR and asthma was found in 8- to 12-year-old children in Austria and Germany if the environment was rich in trees and green areas, while increased asthma and AR risks were found in "gray" residential environments (industrial areas, densely built-up areas; [66]). Generally, there was a beneficial impact on AR manifestation if early contact with green spaces in children's lives took place in summer rather than in spring [67]. Lifetime exposure of 10-year-olds also reduced sensitization to food allergens and aeroallergens [68].

The underlying mechanisms are again related to the microbiome: In three people, both the nasal and skin microbiome was examined before and after visiting green areas, where they also had direct contact with plants and soil material. Just a single intervention for 15–60 min significantly increased the microbial diversity in the nose and on the skin [69]. After exposure, the nasal microbiota was more similar to that in the air, and the skin microbiome was more similar to that in the soil. Before exposure to urban green spaces, the skin and nasal microbiome tended to be dominated by typical skin bacteria such as *Staphylococcus* and *Corynebacteria*, after which there was an increase in microbial taxa from the environment, e.g., *Sphingomonas*, *Blastococcus*, *Solirubrobacter*, and *Massilia*—all typical soil microbes.

Even indoor plantings, for example, green walls, could positively influence the skin microbiome. When office workers stayed in rooms with indoor green walls for only 2 weeks, they had a relatively higher abundance of the genus *Lactobacillus* and a higher Shannon diversity of the strains Proteobacteria and the class Gammaproteobacteria after 2 and after 4 weeks than their colleagues in rooms without planting [70]. At the same time, the pro-inflammatory cytokine IL-17A in the serum was lower and the regulatory transforming growth factor (TGF)-β1 was higher in the intervention group.

Body hygiene: shower, shampoo, and body lotion

Scene 11: *After a busy day, Gisela treats herself to a long, hot shower. She washes her hair with plenty of fragrant shampoo and uses a foaming, colorful, aromatic shower gel. Gisela uses body lotion to care for her skin after showering.*

Human skin has a slightly acidic pH of 4–6, while the pH of conventional soaps is in the alkaline range between 8.5 and 11 [71]. Syndets, short for "synthetic detergents," on the other hand, have a pH of 5.5–7. They are therefore more similar to the physiological skin pH and are also considered rather environmentally friendly.

As with brushing her teeth, she will also encounter large quantities of SLS when showering and caring for her skin. It is added to numerous hygiene products as a component of soap, shampoo, and shaving foam due to its surfactant properties for cleaning, as foaming agent, and for its thickening effect [4].

In a study with women having sensitive skin, a 24-h patch test with SLS resulted in redness, dehydration, and reduced barrier function in the areas of skin that had been in contact with SLS. Concurrently, the number of pathogenic germs (*Staphylococcus*, *Enterobacteria*, *Pantoea*) increased, while the proportion of skin-protecting bacteria (*Micrococcus*, *Kocuria*, *Corynebacterium*) decreased [6]. This barrier disruption can

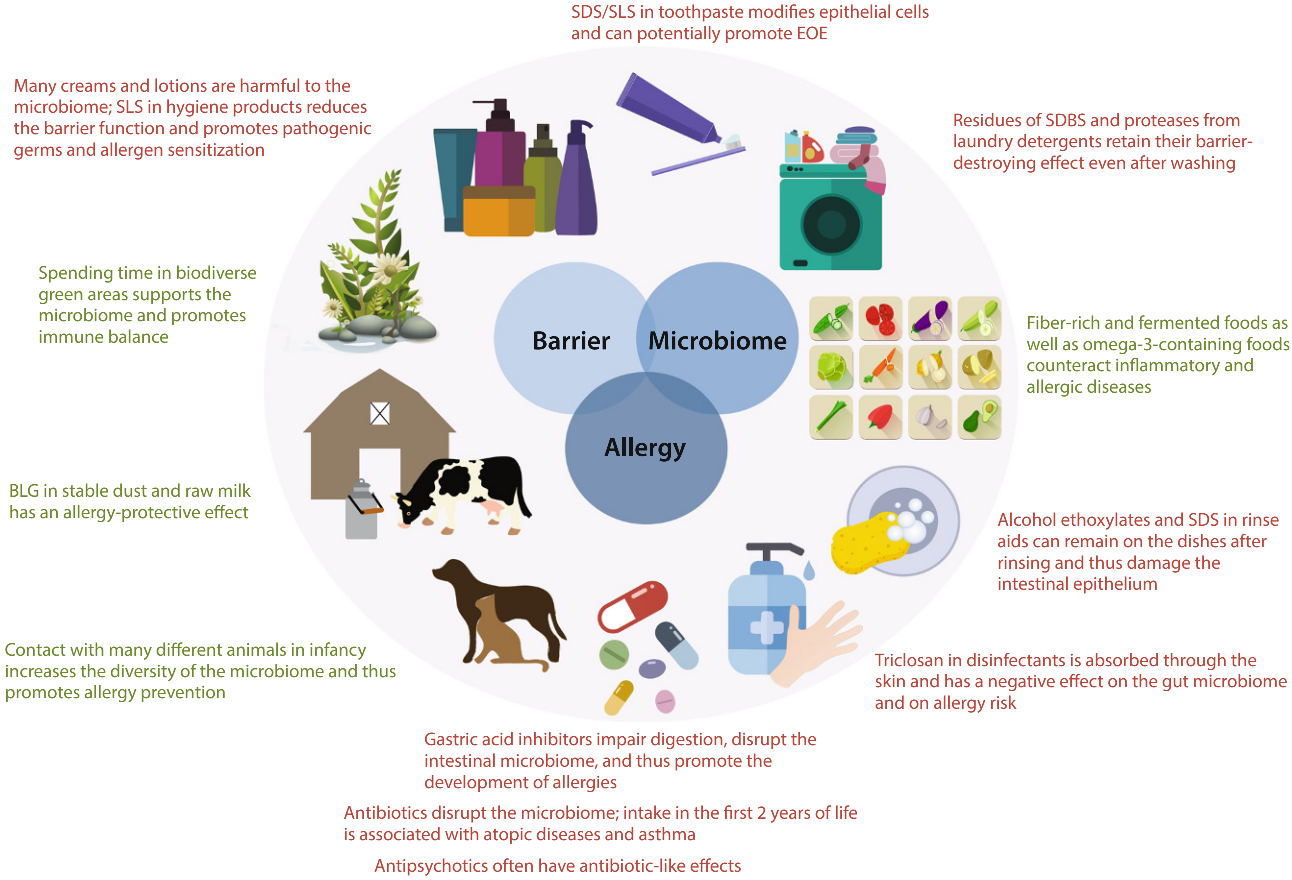

Fig. 1 Many factors that we encounter in everyday life have a positive (*green text*) or negative (*red text*) influence on the barrier and/or microbiome and/or allergy development. *SLS/SDS* sodium lauryl sulfate/ sodium dodecyl sulfate, *EOE* eosinophilic esophagitis, *SDBS* sodium dodecylbenzene sulfonate, *BLG* beta-lactoglobulin. (Sources: The figure was created with Affinity Designer 2. Vegetables, dog/cat: Open-Clipart-Vectors@Pixabay, cow: grafikacesky@Pixabay; plants: Clker-Free-Vector-Images@Pixabay)

subsequently lead to an increased susceptibility for sensitization to allergens or to penetration of allergens into deeper skin layers and thus a higher allergenic potential. Another study investigated the undesirable antibiotic properties of a range of common creams, ointments, and lotions, including some used to treat AD [72]. Of 80 products tested, 77 exhibited antibiotic-like effects, including many that were not marketed as antimicrobials. Chemicals broadly classified as aldehydes, ethers, and metals were more likely to have antibacterial activity than other classes. Only 16% of the substances tested promoted health-associated skin microbes such as *Roseomonas mucosa*, while pathological strains such as *S. aureus* were inhibited. Half of the agents had an indifferent effect on commensals and 34% even proved to be microbiome-damaging and thus AD-promoting.

Different skin care products vary in their effectiveness in restoring the skin barrier or reducing water loss: In adults with AD, three different skin care creams per person were applied twice daily to the lower arms for 4 weeks and skin areas were subsequently challenged with the irritant SLS. It was found that urea-glycerol cream significantly improved the skin barrier and protected against SLS effects. A paraffin-based cream, one of the most commonly prescribed types of emollients, had no effect on the skin barrier. A cream based on glycerol alone performed better than the paraffin-based cream but did not reach the effect achieved in combination with urea [73].

While skin care helps with manifested atopic eczema, daily application of moisturizing skin lotions in the first year of life is not preventive for infants at high risk of developing eczema, asthma, or AR [58, 74]. Creaming as a preventive measure was even associated with an increased risk of skin infections.

In addition, prolonged and/or frequent and/or hot water contact washes out the skin's natural moisturizing factor (NMF). The NMF is a mixture of different molecules and proteins that can store water in the skin; however, as these components are water-soluble, the paradoxical situation arises that frequent contact with water causes dry skin. A recent study showed that the pathogenic germ *S. aureus* occurs more frequently in areas of skin of AD patients where corneocytes have a low NMF, because the binding strength to these is

Table 1 Recommendations for alternative products and lifestyle. Many of the recommendations may not only contribute to the prevention of allergies and other diseases, often they also save resources and money and reduce environmental damage

That's not great	It may be better this way
Plenty of toothpaste with SLS, a large amount is swallowed	Select toothpaste without SLS: less foam, but same cleaning effect [81]; rinse thoroughly after using toothpaste containing SLS
Liquid shampoos, natural soaps, shower gels	Mild soaps and syndets with a pH of 4–6 are not only more skin-friendly [71], they are also available without perfumes and preservatives, sometimes with added probiotics to support the skin microbiome; they can be used for hands and body alike; shampoos and conditioners are available in solid form—some additives can be omitted here (preservatives); easy-to-prepare rinses (e.g., apple cider vinegar water, rosemary water) are equally beneficial for the scalp, hair, and environment
Frequent use of disinfectants, large-area application	Use disinfectants only to the extent absolutely necessary [82], in most cases hand-washing with water and skin-friendly soap is just as effective [83]; quaternary ammonium compounds (Quats) and chlorhexidine are cleaning agents with good antimicrobial properties, effective against SARS-CoV-2, non-toxic to the skin, less irritating than alcohol, and effective for up to 4 h [84]; adhere to skin protection plans (especially if wearing gloves is obligatory); disinfecting normal households is not necessary, especially in bathrooms and toilets modern surfaces are germ-repellent, gentle wiping with citric acid- or acetic acid-based cleaning agents and dry polishing is sufficient
Frequent, hot and/or long showers or baths	A short shower with hand-warm water once or twice a week is often sufficient if there has been no heavy perspiration or exposure to dirt; cleaning armpits, feet, and intimate areas can be done daily with a fresh washcloth [85]
Using large amounts of dish detergent	Use the smallest amount necessary, rinse well; dishwasher tabs can often be halved and then work just as well as a whole tab
Frequent washing of laundry with plenty of washing powder, fabric softener, laundry perfumes	Use the minimum amount necessary [86], excessive foaming can prevent the dirty water from being pumped out of the machine and dirt will reattach to the laundry; jeans, jackets, pullovers, or clothing made from certain materials (such as shirts made from merino wool etc.) can also be worn more often if well aired; other laundry additives (fabric softener, laundry perfumes) should principally be avoided—the fragrances contained can lead to allergies
Chlorinated swimming pools, seawater bathing	After bathing in a swimming pool or seawater, briefly shower with fresh water [87]
Fast food; highly processed, pre-manufactured and pre-fried foods	Seasonal foods, freshly prepared varied meals; omega-3 sources; fermented products such as yoghurt, sauerkraut, kefir, and foods that come largely from plant sources are beneficial for both the gut microbiome and the environment
Stressful lifestyle and consumerism	Take time for eating and enjoy meals, no distractions, regularly consume normal portions
Unnecessary intake of antibiotics	Unnecessary use of antibiotics should be generally avoided, especially against infections that are likely to be viral. However, if antibiotic therapy is unavoidable, care should be taken to choose pathogen-selective antibiotics or combinations to minimize disruption of the microbiome [88]; as most common antibiotics reduce beneficial resident microorganisms (*Faecalibacterium, Bifidobacterium*, and *Blautia*), it is important to consider the route of administration, concentration, and efficacy of antibiotics in clinical practice
Gastric acid inhibitors/acid-suppressing drugs, "stomach protection" without medical supervision	Change lifestyle, eat slowly and regularly, no ice-cold drinks, no physical activity immediately after eating, do not lie down immediately after a meal; if medication that is to be given in parallel with gastric protection is well tolerated anyway (e.g., painkillers), no gastric protection needs to be taken
Long stays in high-purity indoor and/or urban environments	Contact with animals, spending time in parks and green spaces, planting even small areas (windowsill, kitchen garden, balcony, flowerpots), and contact with natural soil promote microbiome diversity (contact without gloves, briefly rinsing hands afterwards is sufficient, no disinfection necessary)

Table 2 Examples of knowledge gaps and questions for future studies

Does swallowing toothpaste with SLS lead to a change in the gut microbiome and, via the gut–skin axis, also to a change in the skin microbiome? Does this dysbiosis then also trigger allergies?
Are there textiles to which detergent residues adhere less well than to others? Which textiles can do with fewer washes and can be aired well (merino wool, hemp materials etc.)?
Do bathing frequency and additives also affect the skin barrier, microbiome and allergy development in adults?
To what extent can moisturizers and care products help (preventively and therapeutically)?
Which is the best composition of green areas and how must contact take place in order to have a beneficial effect on allergy prevention in animals and humans?
How often should contact with ideal green spaces or pets take place and are these contacts also effective in disease prevention for adults?
Are there healthy options among highly processed foods?

increased compared with high-NMF corneocytes [75]. Physical stress, such as intense rubbing or scratching, increases bacterial adhesion, which is mediated by the surface protein clumping factor B (ClfB). The recently published Acari hypothesis postulates that the human eccrine glands play an important role in the defense against mites [76]. If their function and effect are reduced or destroyed by washing with hot water or exposure to air conditioning, the defense against Acari species, i.e., mites and ticks, and *S. aureus* could be impaired—all these species can contribute to the development of allergies.

Medication: antipsychotics

Scene 12: *Gisela goes to bed, she is very tired, but sleep won't set in.*

To better control her current sleep disorders, Gisela takes a low-dose antipsychotic. Non-antibiotic drugs have recently been linked to changes in the composition of the gut microbiome [77]. A study examining more than 1000 marketed drugs against 40 representative strains of intestinal bacteria found that 24% of drugs with human targets inhibited the growth of at least one strain *in vitro*. Among the numerous representatives of all therapeutic classes tested, antimetabolites (used as chemotherapeutics and immunosuppressants), antipsychotics, and calcium antagonists showed anti-commensal effects. Their molecular targets in humans are often conserved in bacteria, which explains the observed antimicrobial effect. The effects of drugs on gut bacteria are also reflected in their antibiotic-like side effects.

One study showed that the intake of escitalopram, a commonly prescribed and effective [78] serotonin reuptake inhibitor, also led to a reduction in the microbial diversity and function of the gut microbiome [79]. Although not yet researched, a link between this antidepressant-induced dysbiosis and the development of allergies is likely.

By contrast, a recent study showed that the composition of the gut microbiome is primarily influenced by the underlying mental disorder itself rather than by the intake of psychotropic drugs [80].

Conclusion

In our everyday lives, we encounter numerous factors that can influence the human microbiome—from nose to gut to skin—and also the barrier of our skin and mucosa (Fig. 1), many of them not in a positive way. For example, ingredients in toothpastes, shaving foam, disinfectants, and shampoos as well as cleaning and rinsing agents for dishes, laundry, and surfaces can increase skin permeability. Various medications target our commensals and lead to dysbiosis. Many of these components have a certain relevance for the function of the respective products, such as increasing cleaning efficiency. The different drug classes, from antibiotics to antipsychotics, often have a life-saving significance in medicine.

However, reducing the use and frequency of applications to a minimum and switching to more skin- and microbiome-friendly products or procedures wherever possible can potentially reduce the risk of atopic and allergic diseases (Table 1). The lifestyle also contributes profoundly to the allergy risk and its minimization: from diet and exercise to contact with pets, biodiverse green spaces and farms, there are numerous points of intervention. Some of these factors should also be considered in medical consultation for the prevention of asthma, allergies, and other diseases and communicated to the population. However, much is still unknown and needs to be clarified in future studies (Table 2).

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