Journal of Wound, Ostomy and Continence Nursing

A review of the impact of microclimate on skin health with absorbent incontinence product use

--Manuscript Draft--

Manuscript Number:	JWOCN-D-18-00021
Article Type:	Original Article - Continence
Section/Category:	Continence
Keywords:	microclimate; skin health; incontinence-associated dermatitis; IAD; occlusion; absorbent incontinence products; urinary incontinence; fecal incontinence; breathability; humidity; temperature
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Manuscript Region of Origin:	UNITED KINGDOM
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To the editor,

Re. Submission of manuscript titled, 'A review of the impact of microclimate on skin health with absorbent incontinence product use'.

I confirm that all listed authors – Shabira Abbas, Christine Stridfeldt, Alan Cottenden and I (Sabrina Falloon) – meet authorship criteria and have participated sufficiently in the work to take public responsibility for the content. This includes planning, literature searches, analysis of evidence, writing and editing the manuscript.

The *Acknowledgements* includes mention of those who have made substantial contributions to the work reported in the manuscript but who do not meet the criteria for authorship.

This material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the *Journal of Wound, Ostomy and Continence Nursing*.

All potential conflicts of interest and funding disclosures have been declared.

Kind regards,

Sabrina Falloon

A review of the impact of microclimate on skin health with absorbent incontinence product use

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Acknowledgements: We are grateful to Professor Katherine Moore and our UCL and SCA colleagues for some stimulating discussions and their critical review of several drafts.

Conflicts of Interest and Source of Funding: This work was funded by SCA Hygiene Products AB, Gothenburg, Sweden and two of the authors (Shabira Abbas and Chatrine Stridfeldt) are SCA employees. There are no other conflicts of interest.

Abstract

This review considers the role of skin occlusion and microclimate in incontinence-associated dermatitis (IAD), with a particular focus on disposable, bodyworn, absorbent incontinence products. Although the mechanisms are not fully understood, the primary causes of IAD are well-established: occluded skin, in prolonged contact with urine and/or feces and exposed to abrasive forces, is more likely to be affected, and each of these factors can be influenced by wearing absorbent incontinence products. Studies comparing the effect of various absorbent products on skin health have often been hindered by the many differences between compared products, making it difficult to clearly attribute any differences in performance to particular materials or design features. However, the large and significant differences that have sometimes been found invite further work. Breathable backsheets can significantly reduce the temperature of occluded skin and the humidity of the adjacent air, and several treatments for nonwoven topsheet materials (used next to the skin) have been shown to impart antimicrobial properties in the laboratory, but an impact on IAD incidence or severity has yet to be demonstrated directly. Recent work to introduce sensing technology into absorbent incontinence products to reduce the exposure of skin to urine and feces, by encouraging prompt product changing, seems likely to yield measurable benefits in terms of reducing incidents of IAD as the technology develops. Published work to date suggests that there is considerable potential for products to be engineered to play a significant role in the reduction of IAD among users.

1. Introduction

Worldwide, more than 200 million people suffer from urinary and/or fecal incontinence [1]. Much incontinence can be cured by treating the underlying causes but complete cure is not always possible; then, the most common way of managing any remaining leakage is to use disposable, bodyworn, absorbent products, which can bring substantial benefits to health-related quality of life[2]. However, product users can sometimes experience incontinence-associated dermatitis (IAD) and there have been some efforts to understand what role occlusion of the skin, in general, and wearing absorbent incontinence products, in particular, may have on skin function~~. But~~ much is as yet unclear. The aim of this paper is to review and summarize pertinent published work to date, focusing particularly on the role of the microclimate established next to the skin in the diaper area when the skin is occluded.

A search of published research was conducted with *Scopus* using the terms shown in Table 1 and process shown in Figure 1. No date restriction was applied, but only publications written in English or Spanish were considered. Next, the set of publications identified by the search was reduced to a subset of just those presenting new or particularly relevant information, by examining their abstracts. Finally, any additional publications found in the reference lists of this subset of publications were considered: abstracts were obtained for any of interest; and full publications obtained where abstracts promised useful information.

2. Incontinence-associated dermatitis

All of the functions of normal healthy skin (Box 1) may be disrupted by incontinence-associated dermatitis (IAD), defined by a 2007 international consensus panel as *"skin inflammation manifested as redness with or without blistering, erosion, or loss of skin barrier function that occurs because of chronically or repeated exposure of the skin to urine or feces"* [3]. IAD is a type of moisture-associated dermatitis and it can occur – or worsen – when the skin is occluded[3,4,5]. Friction between skin and a contact surface is also a likely contributor[6]. IAD is thought to be more common among elderly people and those with reduced mobility[4,7]. IAD is often confused with other conditions, such as pressure ulcers or other types of dermatitis[6,7], making it difficult to estimate its prevalence accurately. However, figures ranging from 5.7% to 52.5% have been reported in the literature[8,9], the rate varying with the care setting and the prevalence, types (urinary and/or fecal), and severity of incontinence, and frailty of the study group. However, most attention has been focused on frail elderly populations in hospitals and nursing homes.

IAD often has wider implications than the immediate discomfort experienced by those who develop it. There can be an increased risk of infection and pressure ulcer (PU) development[6], disruption to daily and/or nightly routine, overall deterioration in quality of life, and greater care costs for patients and/or care providers, primarily associated with deployment of healthcare staff and other caregivers[10]. Matters are further complicated if the condition is misdiagnosed or treated inappropriately[6,11].

3. The impact of occlusion on skin health / microclimate

In equilibrium conditions, the temperature and hydration level of the skin surface are determined by the temperature and humidity of the adjacent air and any air currents, and the skin's equilibrium temperature and hydration level are maintained by the skin losing water and heat to the outside world at the same rates at which they are replenished from the underlying tissues. However, occluding the skin – with an incontinence product, for example (see Figure 2) – can change the balance by hindering the flow of heat and/or water vapor from the skin into the atmosphere, and/or shielding the skin from the ambient air currents that generally encourage heat and water loss from exposed skin[11, 12]. As a result the air in the space between product and skin may be warmer and considerably more humid than it would be next to exposed skin. Indeed, even normal underwear and outer clothing will have some effect on the microclimate next to the skin, as will the thermal properties and water-vapour permeability of any adjacent support surface, such as a chair or bed. A warmer and damper microclimate created by occlusion – combined with the potential presence of urine and/or feces – can have a number of inter-related effects on skin function, and the potential development of IAD. In general, the stratum corneum may become overhydrated, the skin pH rise[4, 13, 14], the activity of enzymes and microbes increase, the skin barrier function reduce and the skin become more susceptible to mechanical damage, as discussed below.

3.1 Overhydration

If the humidity in the microclimate next to the skin is raised, the rate of evaporative water loss from it falls and the stratum corneum becomes overhydrated, impairing its mechanical integrity, as well as affecting its biochemical composition and processes, and its ability to act as an effective barrier[15]. This is partly due to hydration-related changes in the structure of the stratum corneum, but it is also influenced by the nature of any liquid or solution (and its solutes) on the skin surface[16]. In the case of IAD, the common interacting fluids are urine, sweat, water vapor and liquid feces. Sweat and water vapor are present in excess when there is a build-up caused by occlusion, while any urine and/or feces not drawn away into the product's core will remain in contact with the skin, until the next product change. The extent of skin hydration and any subsequent damage also depends on how long skin and fluids are in contact[16].

In fact, exposure to water alone increases the permeability of the stratum corneum, suggesting that overhydration facilitates the passage of irritants – and other potentially harmful substances – across the skin barrier. Indeed, water may be a skin irritant itself: it has been shown that occlusion of skin with water-soaked patches can induce inflammation[17]. Absorbent hygiene products that maintain a healthy microclimate close to the skin could reduce such negative effects.

Middleton[13] has shown that untreated (human and guinea pig) stratum corneum draws water from low concentration saline and loses it to high concentration saline, suggesting water transport by osmosis and that stratum corneum would respond similarly to urine on its surface. Subsequent work by Middleton[14] and by Gerhardt *et al.*[18] supports the conclusion that water enters and leaves the stratum corneum by osmosis.

Warner *et al.*[16] investigated the overhydration of human skin with water and urine, monitoring the process with electron microscopy, and recorded an increase in stratum corneum thickness of 300% after four hours overhydration, and 400% at 24 hours. There was also evidence that some urine solutes entered the stratum corneum, and accumulated in "pockets" in the intercellular space. It is known that the penetration of such irritant substances can trigger an inflammatory reaction that eventually leads to dermatitis[16]. Further, when skin is overhydrated, the rate of water vapour loss from it is restricted by the occluding material and the excess water remains in the stratum corneum, leaving the skin vulnerable to damage for a longer period of time.

3.2 pH

Occlusion appears to increase skin pH[19,20]. A low pH at the skin surface is favorable for the skin's processes, as well as its microflora[21]. If skin pH is raised after prolonged occlusion, the growth of pathogens (such as *S. aureus*) generally increases[19] because a pH close to neutral is optimal for their activity, whereas resident skin flora thrive in acidic conditions[22]. Skin pH is further affected by a number of factors like skin moisture, sweat, sebum and anatomical site. However, sweat production has been shown to contribute to lowering skin surface pH[22].

Shigeta and colleagues[23] investigated the properties of intact skin – in the region usually covered by underwear – and identified microclimate factors important to skin health. The study included elderly women who had UI *and* FI or FI alone, wore absorbent products for long periods of time, and required assistance when changing them. They found that the pH and hydration levels of the skin were significantly higher for participants with double incontinence, rather than FI alone. There was also a clear and significant decrease in coccygeal skin surface pH and absorbent product surface pH with increasing sweat for the doubly incontinent group. All of this highlighted the potential impact of absorbent incontinence products on skin health and the importance of their design, although Shigeta *et al.* did not compare product designs in their study.

3.3 Skin temperature

Occluded skin is impaired in its capacity to allow dissipation of excess heat, so increasing the skin temperature, and a higher skin temperature promotes microbial growth, so increasing the risk of infection[24]. The rate of migration of any skin irritants into the skin also increases[25], as does sweat production which, in turn, increases the humidity of the microclimate. Tissue metabolism and oxygen consumption are also elevated[26]. Limiting this occlusion-associated temperature increase provides some protection and appears to help to maintain the integrity of the skin when exposed to pressures over a given length of time[27].

3.4 Skin barrier function

Microclimate conditions can have a direct impact on the barrier function of the skin. Changes in skin structure, as a result of overhydration – possibly combined with friction or pressure – can leave the skin vulnerable to biochemical degradation and microbial infection, and microclimate conditions can affect the extent and rate of this damage[28]. Dehydration of the skin – for example, by the application of detergents, or by removal of the stratum corneum through abrasion damage – can also impair cutaneous barrier function[29].

Moisture on the skin surface is key to the survival of its microflora and a highly humid microclimate encourages microbial colonization[19]. A relatively high pH at the skin surface can also enable enzyme activity that leads to accelerated desquamation and the colonization of harmful foreign microflora[19]. In addition, different microorganisms thrive in different temperatures, and levels of humidity and oxygen[28]. Cove *et al.*[28] investigated the impact of oxygen concentration on cutaneous microflora and extracellular enzyme production and found that a species that naturally colonized in very humid regions, like the groin and rectum, showed growth in both aerobic and anaerobic conditions[28]. These observations underline the importance of implementing preventative treatment as soon as possible: microclimate changes are invisible and there is generally a delay before their impact – erythema, maceration, etc. – becomes apparent.

3.5 Mechanical considerations

When the skin is occluded it may also be subject to a pressure perpendicular to the skin surface (for example, if an absorbent incontinence product is positioned between the wearer and their bed or chair), or to friction forces (for example, if the product is pulled across the skin surface when the wearer changes posture). Both can affect skin function, in combination with occlusion. Evidence suggests that pressure on the skin contributes more to the formation of pressure ulcers (PU), and frictional forces more to IAD, although each may play a role in both conditions[11]. Friction increases when skin is wet[30] and overhydrated skin is more susceptible to damage by abrasion[12]. Indeed, there is evidence that vigorous rubbing or use of a rough cloth is detrimental to IAD skincare, when cleansing the skin with soap and water[11].

It has been suggested that IAD could increase the risk of PU development[6], but there is little data to support the causal link. Conversely, many studies have reported an association between moisture or incontinence and PU development[31].

3.6 Skin care

There is an extensive literature describing skin care regimes that aim either to prevent IAD occurring or to treat it when it occurs. The primary focus has been on structured skin care regimes that aim to preserve or repair the barrier function of the stratum corneum[6,11]. Various regimes have been tested and investigators found that this kind of intervention significantly reduces the incidence and severity of IAD for a wide range of products, methods and outcome measures[5,11]. Although these methods aim to heal the skin or prevent the manifestation of IAD, they do not tackle the root of the problem. Furthermore, there is the danger of some skincare products interfering with the function of absorbent incontinence products, for example hydrophobic liquids may find their way on to product surfaces impeding the entry of urine[5].

4. The role of absorbent incontinence product materials and design features

The aim of much recent development work on absorbent incontinence products has been to enable them to create healthier microclimates for the skin that they occlude. Products can differ a great deal in the details of their design and structure but they invariably contain an absorbent core sandwiched between a water-permeable topsheet next to the skin, and a water-impermeable backsheet (Figure 3), and most work has related to these key product components. However, it is difficult to draw robust conclusions from the literature: first, the number of published studies is small; second, the diversity of methodologies used hinders comparisons between studies; and third, the products being compared in a given study invariably differ in too many ways for it to be possible to separate out with confidence the impact of individual design features or materials.

4.1 The backsheet

Traditional backsheet materials (usually polyethylene) are impermeable to water in both liquid and vapor forms. By contrast, breathable backsheets combine impermeability to liquid water with permeability to water vapor and air. This is to the potential benefit of the microenvironment between the product and the wearer's skin (see Figure 4), since excess water vapor there can more easily escape to the outside. Although an extensive literature confirms the ability of breathable fabrics to deliver improved comfort and skin dryness in sports, protective and all-weather clothing[32], rather less data is available on breathability in the context of incontinence products.

Runeman and colleagues[33] conducted a ~~cross over~~ trial in which they measured temperature, surface wetness, pH and TEWL (Transepidermal Water Loss – a measure of skin hydration), on the vulvar skin of 12 healthy female volunteers (32-45y) after they had been wearing panty liners of three different designs, or none at all, in random order. Of the three panty liners, one was of standard design with a non-breathable backsheet; one had a breathable backsheet; and one had a slightly thicker absorbent core acidified (to pH 4.5) by superabsorbent polymer, with a non-breathable backsheet. In most cases, temperature, TEWL and pH were significantly lower for breathable panty liners than non-breathable. The same team subsequently repeated the study with a larger cohort of 102 women and reached the same conclusions[34].

More recently, Guo and colleagues[35] – working with a cohort of 20- to 26-year-old female volunteers wearing dry absorbent incontinence products – showed that the rates of heat and water vapor transfer from the skin to the outside of the product were higher for a reusable brief, containing a disposable absorbent product, backed with a breathable waterproof (Nylon) fabric than for a disposable absorbent brief with a non-breathable waterproof (polyethylene) backsheet. They also ran mathematical simulations and found good agreement between simulation and experimental data. Although the products differed in too many ways to attribute differences in performance to particular features, the study did show that big differences are possible, suggesting that further work could be fruitful.

Beguin and associates[36] switched a cohort of 12 patients who had IAD (following use of a "standard" commercially available absorbent product) to an experimental product, and monitored their health for three weeks. The experimental product had breathable side panels and a core containing curled cellulose fibers intended to improve the absorption and distribution of urine. By the end of the study, two thirds of participants were completely free from skin lesions. In parallel laboratory work, after the introduction of water or normal saline, the experimental briefs had considerably lower surface pH values than the product previously used by the subjects, and the breathable nonwoven panels demonstrated high permeability to air and water vapour. However, the clinical study was not controlled and the product used by subjects prior to the project was not described.

In another small randomized crossover trial, Tamai et al.[37] asked six healthy young female adult volunteers to compare the comfort of two different products, and measured the temperature and humidity next to their skin at three locations where pressure ulcers commonly develop (coccygeal, suprapubic and left iliac regions). When subjects wore an insert held in place by mesh briefs, lower humidity was recorded at the skin sites than when they wore an all-in-one diaper, although the difference was statistically significant in only one of the three locations. With both products, skin temperature increased at a similar rate with wear time but absolute temperature and humidity values were not reported.

4.2 The topsheet

Most of an absorbent incontinence product's contact with its wearer is between their skin and its topsheet, and so the impact of topsheet properties on skin has received some attention. However, topsheets have other vital functions: they must also help to hold the product's absorbent core in place, and allow the ready passage of urine through to it. Most topsheets are light-weight, nonwoven fabrics comprising sparsely distributed fibers, held together by thermal, chemical or mechanical bonding. The polymer(s) used for fibers, their cross sectional shape, the finishes intended to change fiber hydrophilicity, the area density of the resultant fabric – and many other manufacturing parameters – may be varied, in pursuit of target properties.

There appear to be no published studies that compare different topsheet materials for their impact on skin. However, based on the understanding of links between pH, enzyme activity and growth of microflora, Shigeta *et al*, suggested that making topsheets from fibers that either had antimicrobial properties themselves – or had an antimicrobial coating – may reduce microbial growth in incontinence products, and they suggested the development of absorbent products with pH control[23]. The development of nonwovens with antimicrobial properties has been attempted in other products, such as surgical masks, where coatings of a halogen copolymer on polypropylene fibers has been tested and proved to be successful[38,39]. Cerkez *et al.* coated and chlorinated (with household bleach) two nonwoven fabrics (of different area densities) used as surgical masks, before testing their antimicrobial properties[38]. The chlorinated samples showed a million-fold decrease in *S. aureus* and *E. Coli* species and the coating worked better on the fabric with the higher area density. The authors concluded that their fabrics held the potential to impart antimicrobial properties to diapers[39].

In a similar study, Radić *et al.* applied a silver coating to polypropylene nonwoven fabric samples (with and without an associated plasma treatment) and compared their antimicrobial properties with untreated fabric samples using three microorganisms (*E. coli*, *S. aureus* and *C. albicans*) in an agar diffuse test[40]. Those samples which had received a plasma treatment (of which there were two types) in addition to silver-loading demonstrated significant antimicrobial activity due – the authors suggested – to the additional silver ion uptake achieved with the combined plasma treatment. Silver-loaded samples which did *not* receive a plasma treatment also showed some microbial resistance, but the inhibition zone was considerably narrower and there was no evidence of antimicrobial activity at all with *C. albicans*. Of the three microorganisms, the *E. coli* was the most sensitive to the silver ions, suggesting that the approach held promise for a role in incontinence products.

4.3 The absorbent core

To be effective, an absorbent core needs to receive urine readily, distribute it efficiently and retain it effectively until the incontinence product is changed. As reported in section 4.1, Guo *et al.*[35] used a combination of mathematical simulations and experiments with volunteers to compare heat and water vapor transport from the inside to the outside of two different absorbent incontinence products. Differences in performance were recorded but the products differed in too many other ways to separate out the impact of their differing cores.

Sugama *et al*.[41] investigated the effect of core material distribution in an absorbent incontinence product using a randomized controlled trial. Half of a cohort of 60 female full-time product-users (aged 65+ years) with UI and IAD used a commercially available product, while the remaining 30 women used an adapted design in which more of the absorbent material was positioned towards the front of the product, with the aim of drawing urine away from the buttock area. The health of the women's skin in the diaper area was monitored using the IAD Skin Condition Assessment Tool 3 and the associated ratings were used to determine changes in participants' skin during the study (healing, improvement, no change or deterioration). Women using the adapted product design recovered significantly faster than those using the conventional product: almost half had recovered after a week, compared to a sixth for conventional product users. However, there was no significant difference in stratum corneum moisture content or pH between groups by the end of the study. While adapting the products appeared to help patients to fully recover from IAD, the numbers of subjects deteriorating or showing no change in skin health score were similar for the two groups.

4.4 Other considerations

Products shaped to follow the body's contours may be more comfortable[36] without necessarily having a negative impact on microclimate. In a crossover study reported by Runeman *et al.*[42], 32 female volunteers (aged 23-45y) each trialed two types of panty liners with breathable backsheets, each with a different type of underwear. With one system, both panty liner and tight fitting (thong-style) underwear covered much less skin than in the other system with its more conventional panty liner and underwear. Measurements of skin temperature, TEWL, and pH at the labium majus and perineum, revealed no difference between the regular and tight-fitting underwear and products. The same applied to aerobic microflora. Regardless of fit, a product that occludes a larger surface area of skin will potentially cause more widespread damage. (See Figure 5 for a range of example absorbent incontinence products.) Diaper-style products often have tabs and some nonwoven or water-impermeable material around the waist (see Figure 5e&f), which creates another microclimate in that region[36]. However, if the waist region is *not* occluded by a waterproof backsheet, liquid should escape here with relative ease[36].

There have been considerable efforts to develop sensors which can be placed in or on absorbent products worn by dependent people and alert care staff to the need for a product change. Several systems are now commercially available, intended for use with either baby diapers or with adult products[43]. Given that protracted exposure to urine is known to play a role in IAD, it seems likely that such sensor systems hold the potential for reducing IAD incidence. Several reports of user trials of such systems have been published, identifying the challenges of avoiding both false alarms and over-reporting, and the mixed views of care staff, but also the real or potential benefits of such technologies in assisting incontinence management[43].

However, widespread use has yet to be achieved. No study has yet aimed to demonstrate that using such a system can reduce the incidence of IAD.

There has also been work to develop sensors to detect the presence of feces[44], again with the potential to reduce the time for which skin is under threat if it leads to prompt changing of soiled products.

5. Discussion / conclusions

Although the details of the mechanisms are not yet fully clear, the primary causes of IAD are well-established: skin that is occluded, in sustained contact with urine and/or feces, and subject to abrasion is more likely to be affected. Further, since each of these primary factors can be influenced by wearing an absorbent incontinence product, such products have the potential to exacerbate – but also to alleviate – the problem.

Studies to compare the impact on skin health of different absorbent products have usually been hampered by the compared products differing from one another in too many ways for any differences in performance to be unambiguously attributable to particular materials or design features. However, the large and significant differences that have sometimes been found indicate that further careful study is likely to be rewarded by insights for product design, holding considerable potential for benefit to absorbent incontinence product users.

Occluding the skin impedes the evaporation of water from the skin surface, leading to a humid microclimate and overhydrated skin, which is known to be more susceptible to damage by abrasion and by chemical and microbial attack, all factors in IAD development.

Perhaps the most robust conclusion from published work is that microporous backsheets on absorbent incontinence products can significantly reduce the temperature of the skin and the humidity of adjacent air, and reduce microflora growth, compared with non-microporous backsheets. Given that IAD development is encouraged by sustained contact with urine and/or feces, the use of products designed to minimize such contact, and prompt change of products after incontinence events are likely to be beneficial.

Laboratory studies have shown that a number of treatments can be used to impart antimicrobial properties to nonwoven fabrics, of the kind used as absorbent incontinence product topsheets, but there are no published studies demonstrating clinical benefit. There are no studies providing convincing evidence that particular features of the product core deliver benefits in terms of reducing IAD but given what is known about the significance of skin exposure to urine and feces, it seems likely that product core designs that reduce exposure time are likely to be beneficial. For the same reason, current work to introduce sensing technology into absorbent incontinence products to encourage prompt product changing, so reducing skin exposure to urine and feces, seems likely to yield measurable benefits in terms of reduced IAD as the technology matures.

In conclusion, IAD is a common problem carrying significant costs in both financial and human terms. The mechanisms by which it works – and the exact part that absorbent incontinence products have to play – is not yet well understood. However, published work to date suggests that there is considerable potential for products to be engineered so as to play a significant role in the reduction of IAD among users.

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Boxes, tables and figures

Table 1. Terms used in literature search on Scopus and number of results; **number after filtering for publication type, language and other factors.

<table>
<tr><th colspan="4">Search terms</th><th>No. of results</th></tr>
<tr><td rowspan="11">skin</td><td>overhydration</td><td></td><td></td><td>45; 43**</td></tr>
<tr><td rowspan="4">moisture</td><td>level</td><td></td><td>648; 587**</td></tr>
<tr><td>barrier function</td><td></td><td>170; 125**</td></tr>
<tr><td>irritation</td><td></td><td>252; 209**</td></tr>
<tr><td>occlusion</td><td></td><td>59; 52**</td></tr>
<tr><td>water</td><td>profile</td><td></td><td>1706; 1305**</td></tr>
<tr><td>health</td><td>moisture</td><td></td><td>314; 246**</td></tr>
<tr><td rowspan="3">hydration</td><td>incontinence</td><td></td><td>24; 22**</td></tr>
<tr><td>excess water</td><td></td><td>32; 29**</td></tr>
<tr><td>absorb*pad*</td><td></td><td>4</td></tr>
<tr><td>moist*</td><td>incontinence</td><td></td><td>118; 113**</td></tr>
<tr><td>IAD</td><td>moisture</td><td></td><td></td><td>25; 24**</td></tr>
<tr><td rowspan="3">skin</td><td>temperature</td><td>*continen*</td><td></td><td>189; 119**</td></tr>
<tr><td>microclimate</td><td>continen*</td><td rowspan="2">pad*</td><td>1</td></tr>
<tr><td>health*</td><td>microclimate</td><td>2; 1**</td></tr>
<tr><td>sensor*</td><td>*continen*</td><td>pad*</td><td>skin</td><td>0</td></tr>
<tr><td rowspan="2">*continen*</td><td rowspan="2">pad*</td><td>design</td><td></td><td>567; 477**</td></tr>
<tr><td>breathab*</td><td></td><td>11; 7**</td></tr>
<tr><td>friction</td><td>microclimate</td><td>skin</td><td></td><td>9</td></tr>
</table>

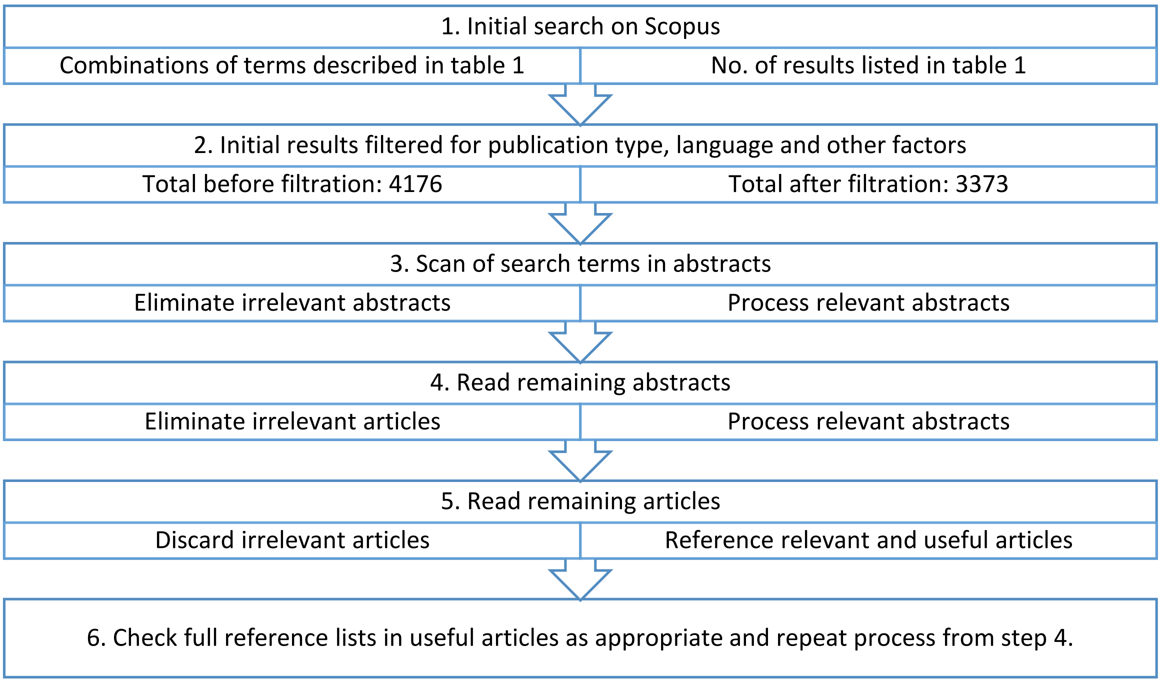


Figure 1. Literature search flowchart.

Box 1. Anatomy and physiology of human skin

Normal healthy skin

The principal functions of healthy skin are: (1) to impede the loss of water and other vital endogenic fluids from the body; (2) to inhibit the penetration of undesirable and harmful external matter and exogenic fluids; and (3) to protect the body under changing environmental conditions (primarily, temperature and humidity), by homeostasis[29]. These functions are best achieved when the skin is intact so that there is minimum interaction between its underlying tissues and potentially harmful substrates and substances in the outside environment. The stratum corneum (the outermost layer of the skin) is particularly important for maintaining its barrier function, creating an almost-completely water-impermeable surface with its 30 or so layers of dead, flattened keratinocytes (corneocytes)[29]. Desquamation of corneocytes provides a passive defense against infection by displacing harmful substances from the outermost surface of the skin[45], and this process is maintained by protease activity which is influenced by such factors as the pH and hydration of the skin[46]. Increased hydration and pH provide more favorable working conditions for the enzymes and, therefore, accelerate desquamation. Normal skin pH is considered to range between 4 and 7 [47] but Lambers *et al.* have shown [47] that it is usually less than 5 when the skin is in a "natural", unwashed state. Local (tap) water, soaps, gels and creams can all affect skin pH.

Some microorganisms – "resident flora" – are consistently found on the skin surface and are considered to exist there naturally, while some are there temporarily – "transient flora"[48]. Resident flora actively protect from unwelcome foreign microorganisms by producing antimicrobial peptides in the skin[46] and by competing with such microbes to inhibit their colonization[47]. The water content of the skin increases with depth, from about 10% hydration at the surface to around 70% at the base of the stratum corneum when it is not occluded[49] and this gradient drives the passive flux of water to the skin surface – a process called transepidermal water loss (TEWL)[50] – where it normally evaporates, depending on ambient conditions.

Skin properties can vary with age, gender and ethnicity. For example, the dermis is known to thin and become less elastic with age[46]; the epidermis also becomes thinner and the dermal-epidermal junction flattens, making it more vulnerable to blister damage[51]. With increasing age, thermoregulation is less efficient and the regeneration of cells slows, so tissue repair also deteriorates. This seems to be counteracted by an increase in stratum corneum thickness and an associated decrease in TEWL[52] – possibly a protective mechanism. Older skin has also been shown to have a higher pH[53,54], lower hydration levels[53] and a higher surface temperature[54]. However, Gerhardt *et al.*[55] reported, essentially, no significant difference in coefficient of friction between skin and contact materials for different age groups.

Interestingly, both coefficient of friction and skin hydration can be greater for women than men – or *vice versa* – depending on the site tested[56]. Finally, it has been demonstrated that black people's skin may be "drier" and less permeable than Asians' and Caucasians' skin, even after the barrier function has been compromised[54], but evidence of ethnicity-related differences is limited. All of these skin functions and properties may be affected by occlusion, particularly if combined with sustained exposure to urine and/or feces, and IAD may result.

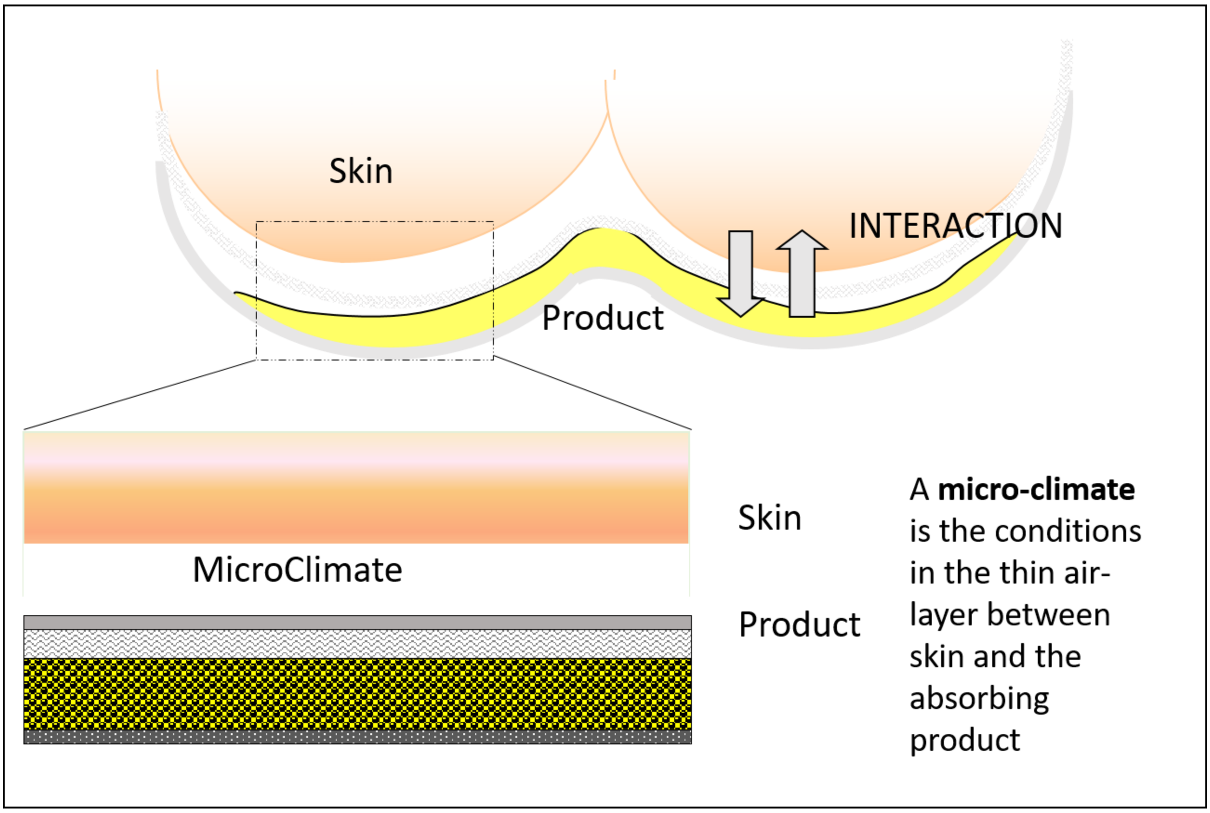


Figure 2 . Schematic of microclimate between skin and example incontinence product.

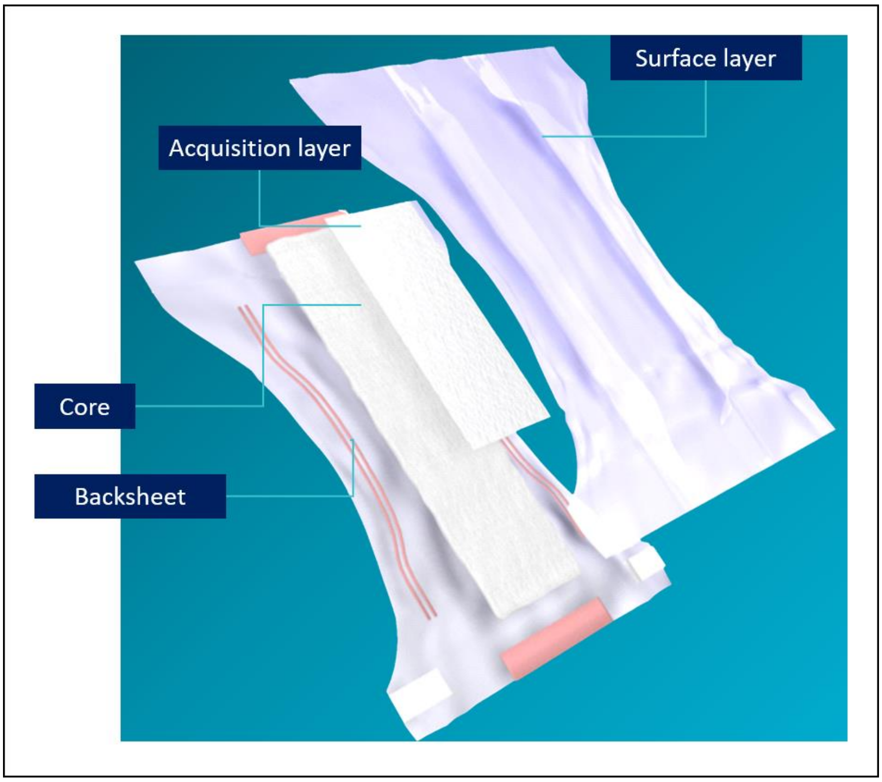


Figure 3. Open incontinence pad.

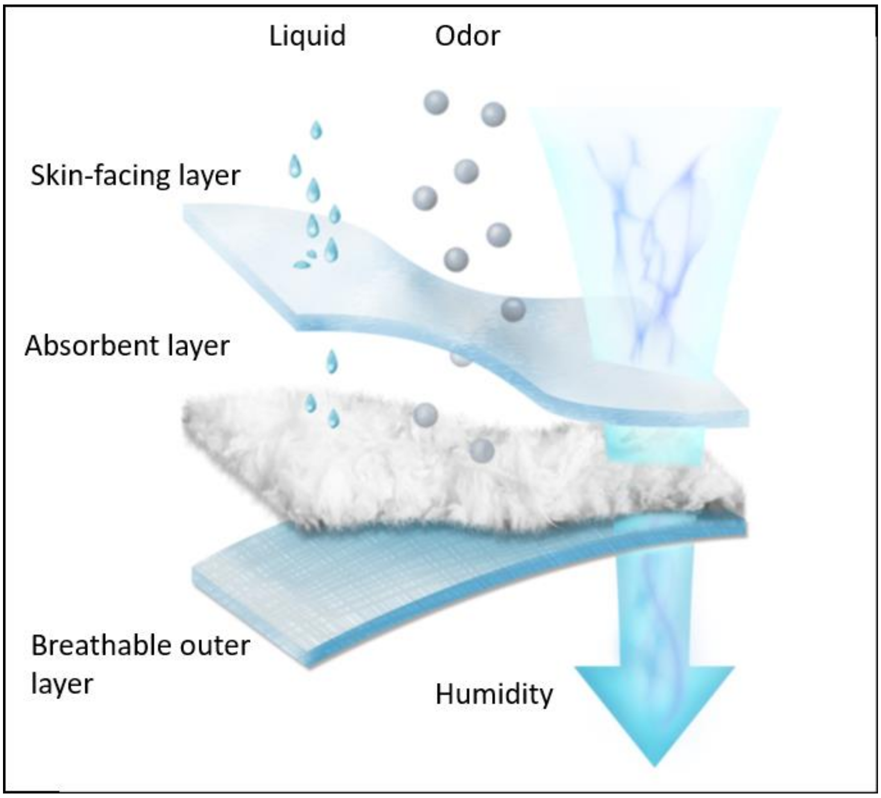


Figure 4. Demonstration of breathability in an absorbent incontinence product.

Figure 5. Examples of absorbent incontinence products for men and women, shaped according to anatomy; (a) selection of different types of pads for women (disposable inserts, washable and disposable all-in-ones/diapers), (b) selection of different types of pads for men (disposable inserts and pouches, washable leaf), (c) disposable pant (pull-up), (d) disposable leaf for men, (e) all-in-one for men and women, (f) t-shaped pad for men and women (adapted from the Continence Product Advisor website[57] with permission).

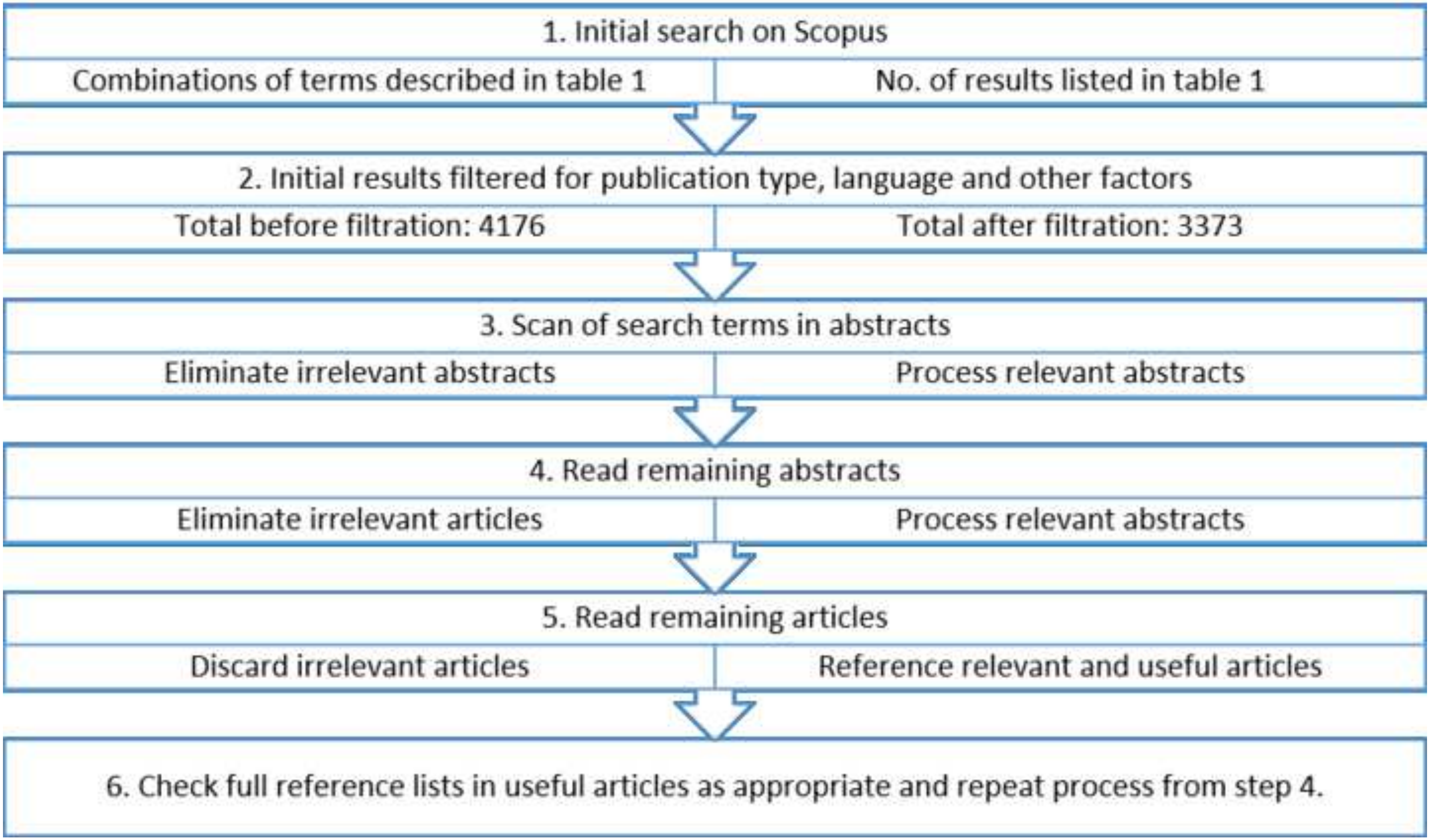
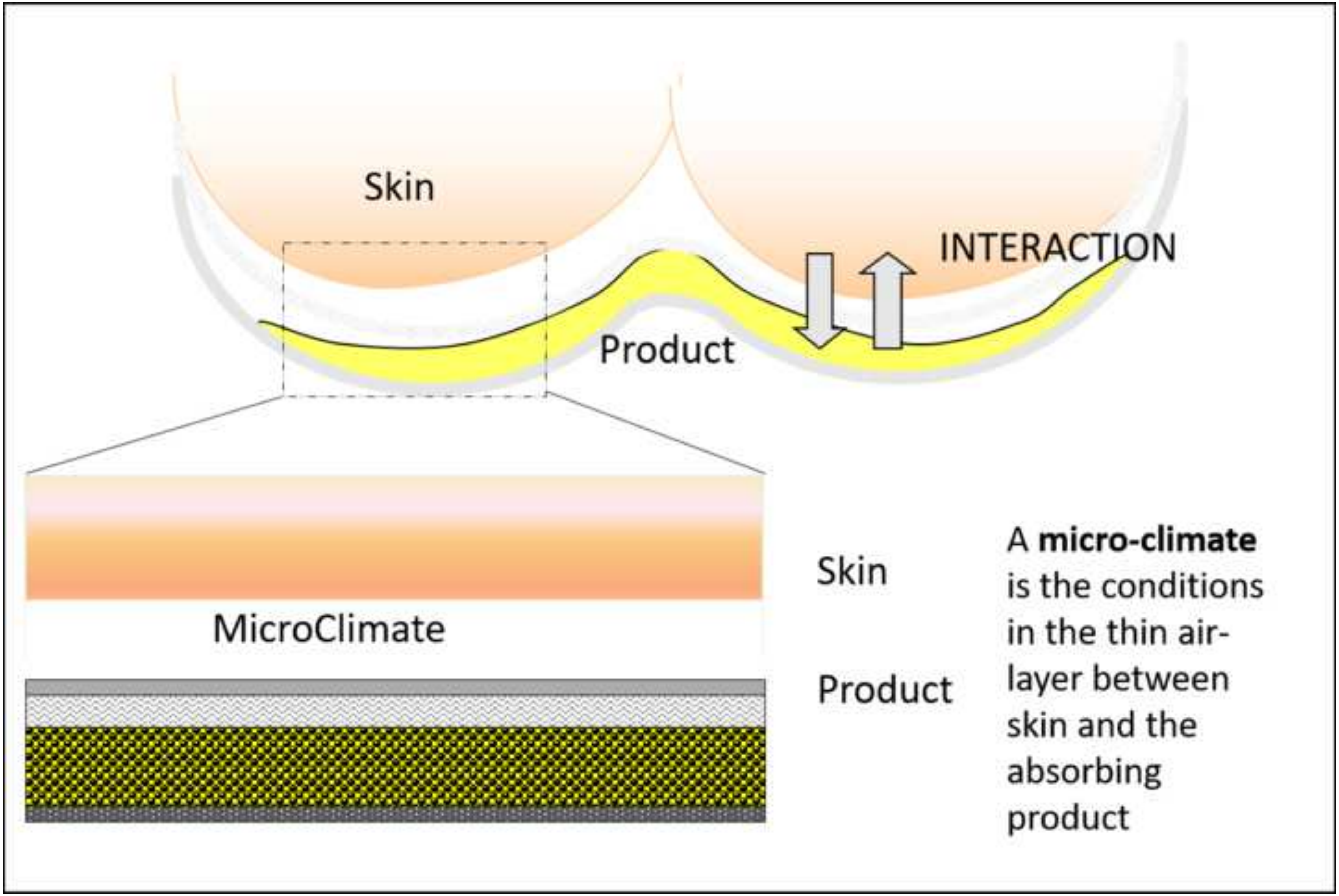
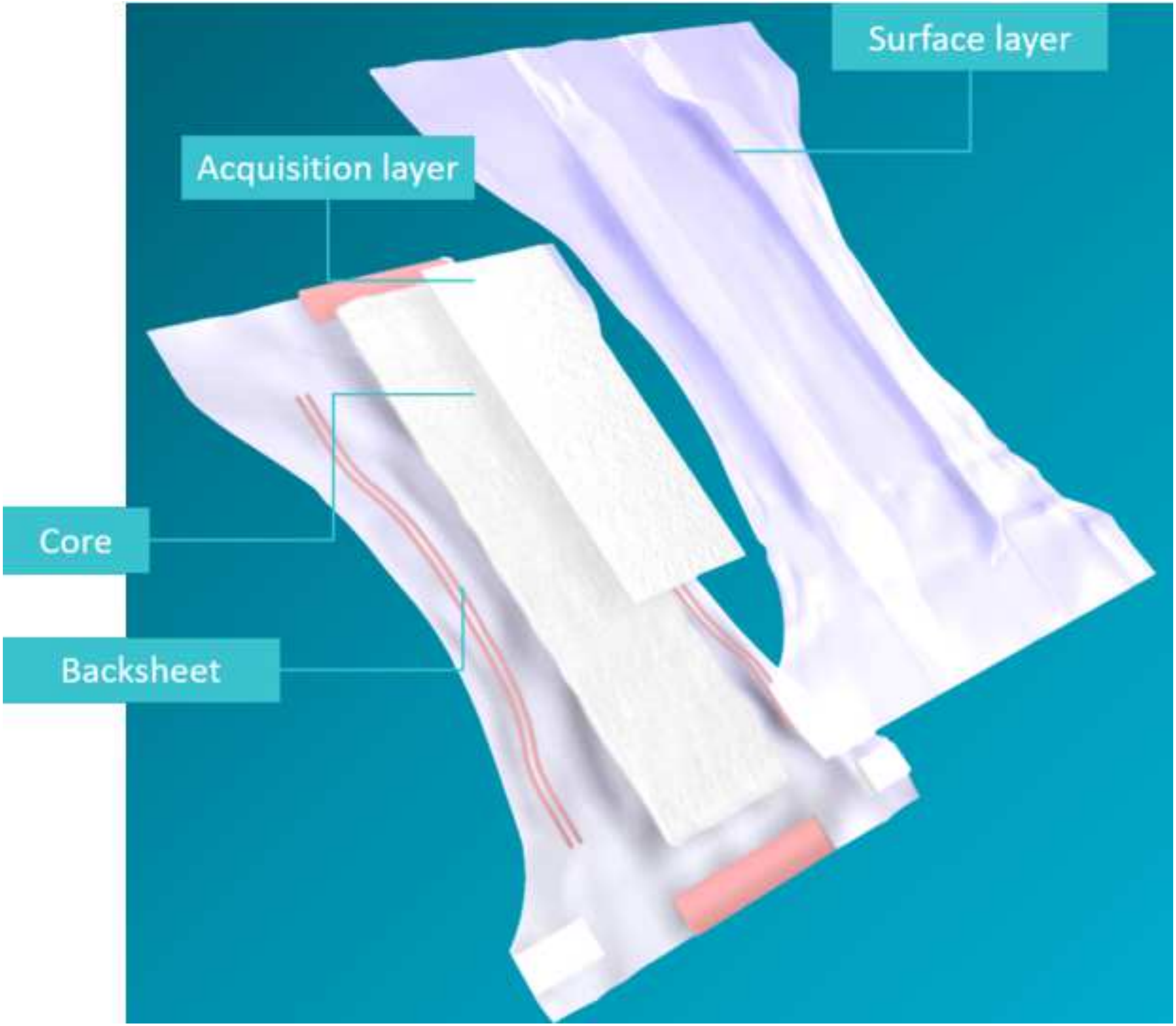
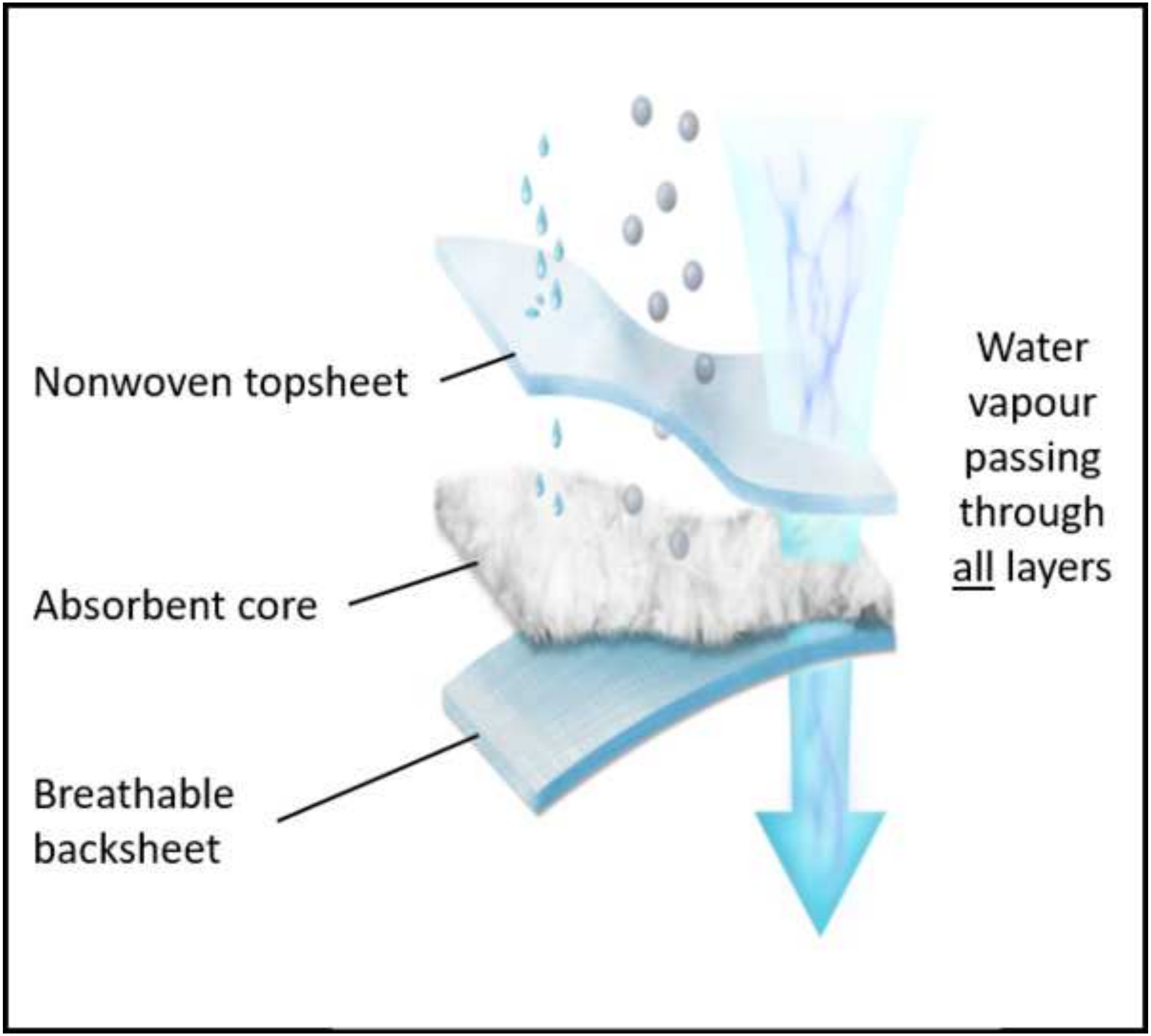

1. Initial search on Scopus
Combinations of terms described in table 1
No. of results listed in table 1
2. Initial results filtered for publication type, language and other factors
Total before filtration: 4176
Total after filtration: 3373
3. Scan of search terms in abstracts
Eliminate irrelevant abstracts
Process relevant abstracts
4. Read remaining abstracts
Eliminate irrelevant articles
Process relevant abstracts
5. Read remaining articles
Discard irrelevant articles
Reference relevant and useful articles
6. Check full reference lists in useful articles as appropriate and repeat process from step 4.

Figure Click here to download Figure Figure 2 - microclimate.tif




Surface layer
Acquisition layer
Core
Backsheet


Nonwoven topsheet
Absorbent core
Breathable backsheet
Water vapour passing through all layers

Figure

Click here to download Figure Figure 5 - absorbents.tif