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ALLERGIC SKIN DISEASES (L FONACIER, SECTION EDITOR)

The Role of Textiles in Dermatitis: An Update

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Abstract Dermatitis has important implications for individuals who are affected. It can significantly impair function and quality of life. Dermatitis is multifactorial and often includes elements of atopic dermatitis, allergic contact dermatitis, and irritant contact dermatitis in a co-existent manner. Textiles are in contact with the human skin for extended periods of time and as a result, they are an important part of the cutaneous environment. Thus, it is not surprising that textiles play a major role in both the etiology and the treatment of various types of dermatitis. This review discusses the role of textiles in dermatitis with an emphasis on interesting and recent advances, trends, perspectives, gaps, and conflicts in the field. In addition, we mention other disease processes to be aware of as they can often mimic textile pattern dermatitis. Lastly, we provide a diagnostic approach for patients presenting with textile pattern dermatitis.

Keywords Textiles · Atopic dermatitis · Allergic contact dermatitis · Irritant contract dermatitis · Disperse dyes · Formaldehyde

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Introduction

Textiles are in contact with the human skin for extended periods of time. Thus, it is not surprising that textiles play a major role in both the etiology and the treatment of various types of dermatitis.

The purpose of this review is to discuss the role of textiles in dermatitis with an emphasis on interesting and recent advances in the field. We approach this discussion by considering the role of textiles in atopic dermatitis, allergic contact dermatitis, and irritant contact dermatitis. While we choose to address these separately, we acknowledge that dermatitis is multi-factorial and often includes elements of each of these subsets in a co-existent manner.

Atopic Dermatitis

Two fundamental aspects in the treatment of atopic dermatitis (AD) are the maintenance of skin hydration (reducing transepidermal water loss) and avoidance of aggravating factors.

It has been recognized that the use of occlusive fibers such as filamentous polyester [1] and nylon [2] in the form of fabrics, athletic equipment [3], gloves, and footwear has the potential to worsen AD. While initially these occlusive fibers promote retention of moisture, their removal in low humidity conditions results in rapid evaporation of moisture from the skin. Pre-existing epidermal barrier dysfunction in patients with AD allows the quick change in humidity to cause fissuring of the skin. Rapid removal of occlusion also upregulates inflammatory cytokines [4]. As a result, it is helpful for AD patients to wear fibers such as cotton or lyocell [5] which wick moisture, by absorbing liquid away from the skin, under occlusive materials. In a randomized cross over study in AD patients and normal subjects which compared participant preferences and itch reduction between 100 % lyocell and 100 %

cotton fabrics, patients had greater preference for 100 % lyocell based on softness, temperature, and moisture control. With regards to itch, lyocell and cotton were comparable [5].

Exposure to certain types of rough fibers is well known to cause aggravation of existing AD [6, 7]. Fabrics such as wool clothing can cause mechanical irritation and exacerbate symptoms of AD [8]. For this reason, the most commonly recommended fibers for patients with AD are smooth fibers such as cotton and silk which have low irritant potential. Further reduction in irritation can be achieved when cotton is functionalized with borage oils which contain γ-linolenic acid which has anti-inflammatory properties and reduces trans-epidermal water loss. Kanehara et al. conducted a double-blind, placebo-controlled trial comparing undershirts chemically coated with borage oil and non-coated undershirts in children with AD. They found a statistically significant improvement in pruritus and erythema in the children in the experimental group as opposed to children in the placebo group [9]. Studies have shown that other smooth fibers such as ethylene vinyl alcohol (EVOH) fiber (commercially available synthetic fiber produced by Kuraray Trading Co. Ltd. (Osaka, Japan)) are also advantageous in AD patients with regards to control of irritation [10]. Yokoyama et al. conducted a double-blind randomized controlled trial in children with AD and found that compared to cotton underwear, EVOH underwear significantly prevented sleep loss and improved pruritus. In addition, they found a statistically significant decrease in urinary cortisol levels in children who wore EVOH underwear and they proposed that EVOH provides a less stressful stimulant to the skin compared to cotton [11].

It is well established that patients with AD have increased susceptibility to colonization with *Staphylococcus aureus* which can also function as a super-antigen. Occlusion from clothing fosters growth of commensal organisms that can act to exacerbate skin inflammation in AD. Thus, efforts in the management of AD have focused on antimicrobial interventions. One way of achieving this is through the use of functional textiles. Functional textiles are textiles which have been imparted with antimicrobial and antipruritic qualities. Silver-coated textiles are the most common [12]. In a controlled, randomized, single-blinded study, Fluhr et al. compared the effects of silver-loaded seaweed-based cellulosic fiber (SeaCell® Active) T-shirts versus cotton T-shirts in 37 AD patients. Evaluation of *S. aureus* colonization in these patients after 8 weeks of wearing either fabric revealed a significant decrease in *S. aureus* colonization in the silver T-shirt group compared to the cotton T-shirt group [13]. Similar studies have produced comparable results with regards to the efficacy of silver-coated textiles in reducing *S. aureus* colonization [14] and significantly improving AD severity measured by SCORAD (SCORing Atopic Dermatitis) index [15, 16, 17•]. An alternative compound which has been found to impart antimicrobial properties to textiles is zinc oxide (ZnO). ZnO also has antioxidant properties which makes it especially appealing for its use in functionalized textiles for the management of AD [18]. In a pilot study with 12 AD patients who wore ZnO-impregnated textiles overnight, the researchers observed a swift improvement in the severity AD and subjective sleep quality in these patients [18].

In summary, patients with atopic dermatitis should be counseled to avoid occlusive fabrics such as filamentous polyester or acetate and to wear fabrics that wick moisture. Fabrics with embedded nanoparticle silver may be useful to control colonization with antigenic commensal organisms.

Allergic Contact Dermatitis

Areas of the skin where significant and frequent perspiration and friction occur and areas which are in greatest contact with the offending textile are more prone to textile induced allergic contact dermatitis (ACD). Moisture in these regions facilitates the release of dyes and resins from fabrics which are then able to penetrate the skin and often through another layer of clothing. Such areas include upper back and posterior thighs (in the case of ACD secondary to bed linens and furniture), antecubital folds, popliteal folds, medial thighs, anterior and posterior axillary lines, waistbands, posterior neck, and upper back (in the case of ACD secondary to apparel) [19–21].

Primary sensitization in cases of textile-related ACD is rarely due to textiles. Often times, primary sensitization occurs via occupational exposure to chemicals which cross-react with allergens found in textiles. The main culprits in the elicitation of textile-associated ACD are dyes and formaldehyde (FA) finishing resins. Common chemicals which result in primary sensitization and the corresponding occupations at highest risk for exposure include exposure to components of hair dye (p-phenylenediamine (PPD), aminophenol, and diaminotoluene sulfate) in hair dressers and formaldehyde in health care workers [22], embalmers, cabinetmakers [23], and machinists. PPD exposure and sensitization can also occur through temporary black henna tattoos. The frequency of induction of a contact allergy with the use of black henna tattoo is approximately 2.5 % [24].

The most common class of dyes implicated in textile-induced ACD is disperse dyes. Ryberg et al. conducted a multicenter study in which they patch tested 2,907 patients with a textile dye mix consisting of "Disperse Blue 35, Disperse Yellow 3, Disperse Orange 1 and 3, and Disperse Red 1 and 17, all at 1.0 %, and Disperse Blue 106 and Disperse Blue 124, each at 0.3 %." Of those patients, 108 patients (3.7 %) were found to have contact allergies to the textile dye mix [25•]. Disperse dyes used to impart color in fabrics are able to cross-react with PPD and can thus induce ACD in patients previously sensitized to PPD. Both intrinsic factors (color fastness) and extrinsic factors (perspiration and friction) play

an important role in determining how much dye from fabric is available to penetrate the skin and thus result in an ACD reaction [19]. The most common fibers to which disperse dyes are added during the manufacturing process are synthetic fibers such as acetate, triacetates, polyester, and nylon [26] (Table 1).

Reports regarding the most common types of disperse dyes which induce ACD varies between studies which likely reflects the apparel marketed to the population studied. Malinauskiene et al. reviewed 54 studies and found that in screening patch tests for disperse dyes, the prevalence of positive patch tests was highest for "Disperse Blue 106 (1.9 %), Disperse Blue 124 (1.7 %) and Disperse Orange 3 (1.2 %)." However, another study in which 2,907 patients underwent patch testing reported that the three most common disperse dyes to elicit a positive patch test reaction were Disperse Orange 3, Disperse Orange 1, and Disperse Blue 106 respectively [27].

European Union and Japanese initiatives to regulate textile allergens discussed later in this manuscript have decreased textile allergy in some countries outside the EU and Japan as well. It is uncertain how often disperse dyes are currently being incorporated into clothing. In 2012, a group of researchers analyzed 121 items purchased randomly worldwide and found that only two items (a pair of ladies' tights and a set of black bra and panties) contained disperse dyes (Disperse Yellow 3, Disperse Blue 124 and Disperse Blue 106 and Disperse Orange 1, respectively) [28••]. Though it is less common, reactive dyes, which are more color-fast and have higher stability, are also capable of inducing ACD [29, 30]. Reactive dyes are more commonly added to natural cellulosic fibers (such as wool, silk, 100 % cotton, and linen), rayon, and polyamides [29] (Table 1).

Table 1 Some textile contact allergens and their sources

Textile contact allergen	Common sources
Disperse dyes	Non-cellulosic fibers (acetate, polyester, and nylon)
Reactive dyes	Natural fibers (wool, silk, 100 % cotton and linen), rayon, and polyamides
Formaldehyde resins	Cellulosic fibers (wool, cotton, and rayon)
Sodium metabisulfite	Jeans
Rubber chemicals (carbamates, thiurams, mercaptobenzothiazole (MCTBZ))	Elastic (Spandex is generally free from these allergens with the exception of MCTBZ in Elastane®)
Chromates	Leather
Cobalt	Clothing dyed with metallic dyes
Corticosteroids, propylene glycol, lanolin, bacitracin, neomycin, and other components of topical medicaments	Mesh of bras, knit parts of socks, and rarely washed garments like jackets

In the 1920s, incorporation of formaldehyde resins into textiles (cellulose fibers and rayon fibers (Table 1)) began, mainly to impart wrinkle-free properties, reduce shrinking, and increase fabric strength for permanent press clothing [19, 31]. Thus, the main application of FA resins is in permanent press clothing [19]. FA resins in permanent press clothing are capable of inducing ACD in individuals who have been previously sensitized to FA [32]. Initially, resins which released large quantities of free FA (5,000–2,000 μg/g or >1,000 ppm) such as urea-formaldehyde resin and melamine formaldehyde were being used for these purposes [21]. However, consideration of the health safety of FA has led to a shift which involves the use of resins such as cyclic ethylene derivatives (e.g., dimethylol dihydroxyethyleneurea (DMDHEU)) which release low quantities of FA (<100 ppm) and ultralow (<30 ppm) quantities of FA in the presence of diethylene glycol [21]. Another ultralow FA releaser is methylated DMDHEU. It has been estimated that in previously sensitized patients, exposure to FA levels of at least 30 ppm in clothing can elicit ACD [23].

Use of textile resins with lower FA release has resulted in a decrease in the occurrence of FA-associated textile ACD. The North American Contact Dermatitis Group (NACDG) patch testing results of 4,308 patients from January 1, 2009 to December 31, 2010 revealed a statistically significant decrease in positive patch testing reactions towards FA and DMDHEU compared to the previous study period (2007–2008) [33••]. However, these changes have not eradicated the existence of FA-induced textile ACD in the USA. This has been a source of debate within the field. In a review article by DeGroot and Maibach, the authors propose that the quantities of FA currently released by textiles bought in the USA are insufficient to cause ACD. Thus, the authors question the existence of FA-related textile ACD in the USA [34]. However, ACD is still commonly seen with highly finished garments such as uniforms including water-resistant laboratory coats, zip-up greens worn by machinists and military wool garments [35, 21]. In addition, a retrospective study conducted in 2012 showed that 8 % of patients who underwent screening patch testing between January 2000 and September 2011 using a textile series had positive patch reactions to melamine FA [36]. Thus, if these group of people are exposed to items which were made when FA releasing resins that release large quantities of FA were still being incorporated in clothing (e.g., vintage clothing and furniture (cotton upholstery)), there exists the potential to elicit ACD.

Recently reported textile allergens include sulfites used to bleach and dye jeans [37]. Aerts et al. describe a case report in which a 41-year-old man developed ACD following exposure to a new pair of blue jeans. Patch testing was negative to a baseline series and textile series but positive to sodium

metabisulfite in a cosmetic series. Chemical analysis of the jeans revealed clinically relevant levels of sodium metabisulfite. The patient's ACD resolved upon avoidance of the pair of blue jeans. Other recently reported textile allergens include mercaptobenzothiazole in Elastane® used in active wear [38], trivalent and hexavalent chromium in tanned leather [39], and cobalt in clothing dyed with metallic dyes [40] (Table 1).

The management of textile-related ACD involves identifying the offending allergens and educating the patient about alternatives to promote complete avoidance of these allergens by the patient. The gold standard for the identification of offending allergens is epicutaneous patch testing. Patch testing options include Thin-Layer Rapid Use Epicutaneous (TRUE) test, extended screening series, and supplemental exposure specific series such as a textile series [41].

There are many limitations with regards to the use of patch testing in investigating textile related ACD [42•]. Currently, the TRUE test consists of only 35 allergens. Out of the multitude of known compounds within textiles that could act as contact allergens, two thirds of them being disperse dyes, the TRUE test contains only one textile dye contact allergen (Disperse blue 106). FA is included in the TRUE patch test, but no FA textile resins are included. It is not uncommon for patients who have contact sensitivity to FA releasing resin to test negative to FA [21]. The limited number of allergens leads to under-detection of contact allergens in patients. Testing to pieces of suspected clothing is often falsely negative as the usage conditions of perspiration and friction that elicit leaching of dyes and resins from the fabric may not be replicated by placing a piece of the textile on the skin of the back.

Patient education and counseling is vital with regards to ensuring avoidance of offending allergens. Patients should be educated about offending allergens and the need to completely avoid allergens. Even brief, infrequent exposure to allergens will prevent resolution of dermatitis. Clothing labels do not specify the type of dye or textile resin used, making it difficult to determine clothing that would be considered safe for the patient. Many manufacturers outsource the production of their garments to multiple countries which do not have textile regulatory agencies. As a result, it is often difficult for the manufacturers themselves to provide an accurate and comprehensive list of the chemicals present in their products.

In the European Union and Japan, regulation of the textile industry by the Oeko-Tex Association allows for the production and identification of clothing that are free from allergenic dyes and high levels of FA release. [28••, 42•]. Such clothing has the Oeko-Tex label and patients with textile-related ACD can be advised to use this label to guide their choice of clothing. In the USA, there is no government regulation of the levels of FA contained in fabrics nor does public data exist regarding the levels of FA in clothing available for sale in the USA. Some US retailers have internal limits on the levels of FA present in the clothing they produce, while others participate in voluntary disclosures on their label concerning the level of FA contained within the clothing they produce [23]. In 2010, the US Government Accountability Office purchased and analyzed the FA levels in 180 fabric items purchased randomly throughout the USA. They found that 5.5 % of these items had FA levels between 75.4 and 206.1 ppm. This surpassed the existing regulations set by other countries that have laws regarding FA content of clothing [23]. Lack of regulatory standards makes it challenging for patients for whom FA is a contact allergen to identify and avoid such apparels.

Patient education for textile allergen avoidance includes restricting contact with any fibers that may contain the allergen. For disperse dye allergic patients, this means avoiding non-cellulosic fibers such as polyester, nylon, and acetate. For FA allergic patients, this means avoiding all cellulosic fibers such as cotton and rayon. The burden of such an approach is great, but is the only way to assure prevention of exposure in the absence of a complete list of components on the product labeling. Other options include reducing perspiration, wearing loose fitting clothing, and wearing a layer of clothing under potentially allergenic fabrics. However, none of the options other than avoidance is guaranteed to prevent elicitation of ACD.

Another approach in the management of textile-related ACD is to prevent the sensitization phase of ACD. This can be achieved by educating workers on skin hygiene and the appropriate use of skin protective gears such as gloves in populations that are at high risk for occupational sensitization. Recent advances have focused on reducing the sensitizing potency of well-known sensitizers in ACD. The challenge in this area has been decreasing the sensitizing potency of such sensitizers without compromising the advantageous properties that the sensitizers impart upon textiles (e.g., maintaining the ability of PPD to impart color in the hair dyeing process). Goebel et al. describe experiments in which altering the molecular structure of PPD by the addition of a methoxymethyl side chain (ME-PPD) resulted in a decrease in the molecule's skin sensitizing ability in vitro and in vivo. These molecular changes did not significantly alter hair dyeing properties of PPD [43]. If fewer people become sensitized to hair dye then, in theory, we may see less elicitation from disperse textile dyes via cross-reaction.

Irritant Contact Dermatitis

Rough, harsh fibers which can cause mechanical irritation are the most common causes of textile-induced ICD [44]. Examples of such rough fibers include the animal-derived fiber, wool, and the vegetable-based fiber, burlap [45]. The severity

of ICD depends on several characteristics of both the irritant and the host. Irritant characteristics to consider include type of irritant, amount of exposure, length of exposure, and frequency of exposure [46]. Host characteristics to consider include age (inverse relationship: susceptibility to ICD decreases with age), sex (increased frequency of ICD in women compared to men), pre-existing cutaneous conditions such as atopic dermatitis (increased susceptibility to ICD in the presence of AD due to pre-existing skin barrier dysfunction), and genetic factors (filaggrin null alleles found in ichthyosis and some cases of AD confer increased susceptibility to ICD) [47–50, 46].

Due to the fact that signs and symptoms of textile-related ICD appear immediately following exposure (minutes to hours), patients rarely seek medical attention and are able to self-diagnose and self-treat by avoiding the offending irritant textile in the future. For the minority of patients who present to a clinician, diagnosis of ICD is based on a thorough history, skin examination, and the absence of clinically relevant allergens on patch testing [51]. The cornerstone in the treatment of ICD is avoidance of the offending irritant textile, although avoidance of irritants does not need to be as absolute as does avoidance of allergens to control dermatitis. Also in contrast to ACD, undergarments which are non-irritants can be worn underneath irritant clothing to prevent direct contact with the skin.

Mimics of Textile Pattern Dermatitis

Sometimes garments themselves may not contain allergens that can cause ACD but instead act as vehicles for the retention of allergens from other sources. In a series of cases, patient avoidance of established allergens did not result in complete resolution of ACD [52]. The distribution of residual ACD in these patients (areas of the skin in greatest contact with clothing) suggested that retention of medicament ointments containing allergens (confirmed by patch testing) in clothing was responsible for the persistence and recurrence

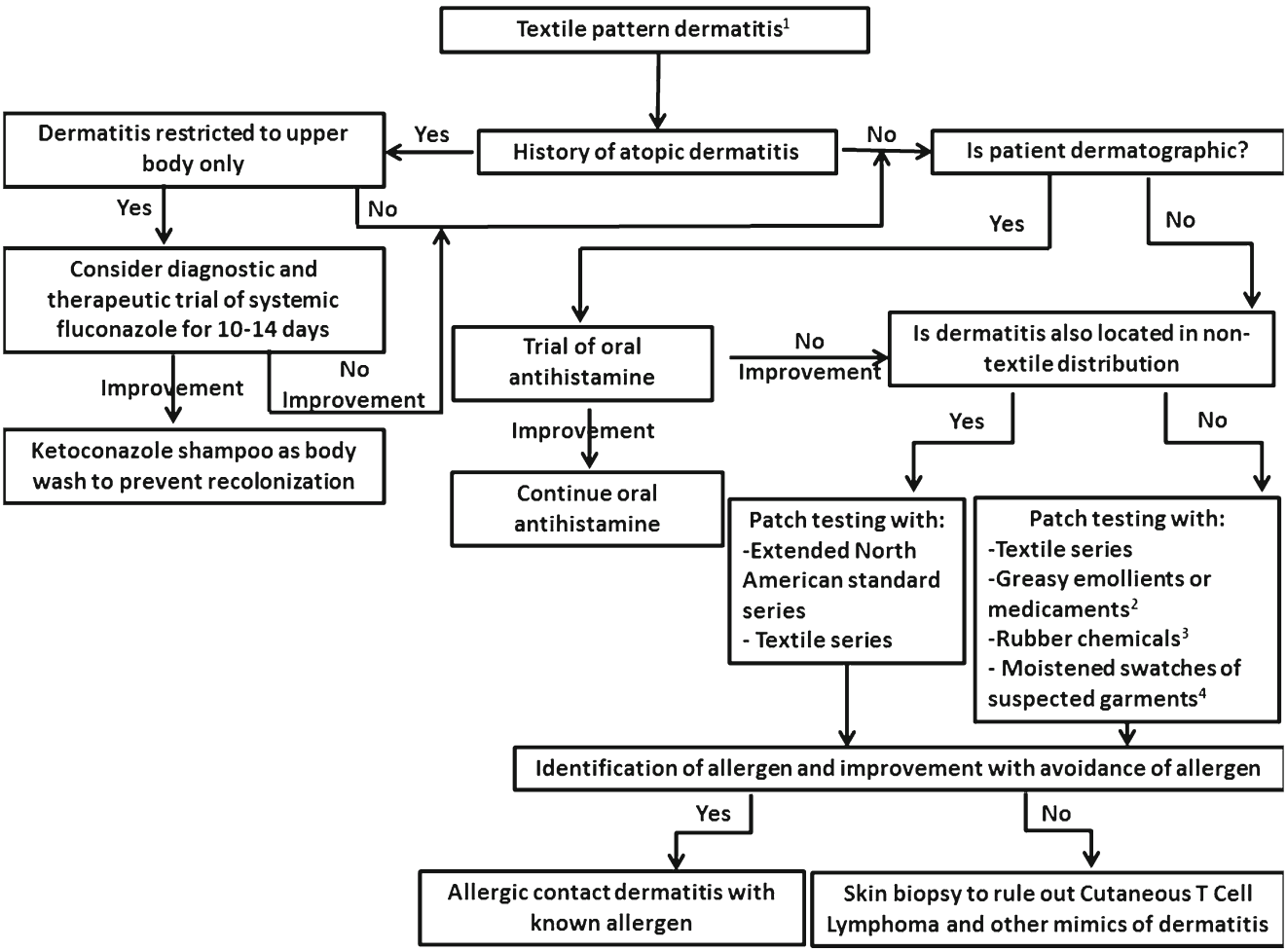

Fig. 1 Diagnostic algorithm for patients with textile pattern dermatitis. *1* Dermatitis located in the antecubital folds, popliteal folds, medial thighs, anterior and posterior axillary lines, waistbands, posterior neck, and upper back. *2* Greasy emollients or medicaments which are pertinent to the patient's history and could potentially be retained in fabric after washing. *3* Rubber chemicals should be tested if areas of dermatitis are in contact with elastic or, in rare instances, Elastane®. *4* If patient consents to potential harm of the garment

of ACD in these patients. Dermatitis resolved with disposal of the contaminated clothing [52]. Thus, if patch testing is indicated in an individual presenting with textile pattern dermatitis, greasy emollients or medicaments which are pertinent to the patient's history and could potentially be retained in fabric after washing should also be tested (Fig. 1).

Some patients with physical urticaria will develop dermatographism in areas where clothing binds tightly. If these areas are excoriated, they resemble ACD in that the crusting from the excoriated erosions persists for days after exposure [53]. The mainstay of treatment of symptomatic dermatographism is oral anti-histamines (Fig. 1). In addition to physical urticaria, allergic contact urticaria can occur. Although there are reports of contact urticaria from reactive dyes in the occupational setting [54], allergic contact urticaria to textile dyes released from garments is rarely recognized.

Patients with atopic dermatitis may flare in areas of *Malassezia* yeast colonization. These areas have sufficient sebaceous activity to create oil to nourish the yeast and are on the upper part of the torso, and the neck and face. Patients with a positive patch test to *Malassezia* yeast often have a textile pattern of dermatitis [55]. These patients improve with the use of systemic azole antibiotics that kill yeast. Thus, in a patient with AD presenting with a textile pattern dermatitis restricted to the upper body, a diagnostic and therapeutic trial of systemic fluconazole is a reasonable next step in management (Fig. 1).

Early on in the disease course, cutaneous T cell lymphoma (CTCL) can have a similar clinical picture to textile contact dermatitis in that CTCL favors photoprotected areas such as those under clothing [56]. As a result, it is a diagnosis to consider when evaluating a patient with textile pattern dermatitis who fails conventional treatment for dermatitis (Fig. 1). Diagnosis of CTCL often requires multiple skin biopsies.

Conclusion

Many people recognize the itch of irritant dermatitis due to mechanically rough fibers. However, dermatitis due to ACD from textiles and aggravation of AD by occlusive fibers is likely under-recognized. Dermatitis is an environmental disease, and textiles are an important part of the cutaneous environment. Patient education regarding optimal apparel is important.

Compliance with Ethics Guidelines

Conflict of Interest Motunrayo Mobolaji-Lawal has nothing to disclose. Dr. Susan Nedorost reports grants from Lenzing Fibers, Austria, outside the submitted work.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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