AMERICAN ACADEMIC PUBLISHER

INTERNATIONAL JOURNAL OF MEDICAL SCIENCES

ISSN NUMBER: 2692 - 5206 Volume 6. No 02. February ,2026

ULTRASOUND IMAGING OF THE SKIN IN THE DIAGNOSTIC ASSESSMENT OF PEDIATRIC ATOPIC DERMATITIS

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Abstract. Atopic dermatitis (AD) is a prevalent chronic inflammatory skin condition in children, characterized by recurrent flare-ups and significant variability in its clinical manifestations. Timely and accurate diagnosis is crucial for optimal management and treatment, as delays or inaccuracies can lead to disease progression, complicating both treatment and prognosis. Traditional diagnostic tools such as clinical assessment, histopathology, and dermatoscopy have been widely used to assess the severity and progression of AD. However, these techniques may not provide a comprehensive picture of the underlying structural changes in the skin. Ultrasound examination of the skin has emerged as a valuable, non-invasive imaging technique that offers real-time insights into the morphological characteristics of the skin affected by atopic dermatitis. By evaluating the skin's echogenicity, thickness, and dermal architecture, ultrasound can provide detailed information on inflammation, edema, and epidermal changes, which are key markers of disease activity. The method's sensitivity in detecting subtle changes in both the epidermal and dermal layers allows for better differentiation between active and chronic phases of the disease. This review highlights the growing role of ultrasound examination in the diagnostic and prognostic assessment of atopic dermatitis in pediatric patients. It explores the technology's utility in early diagnosis, monitoring therapeutic responses, and predicting disease outcomes. Ultrasound's ability to provide objective, quantitative data complements clinical evaluation and contributes to a more personalized and precise approach to patient care. The article also discusses the practical advantages of ultrasound, such as its safety, repeatability, and cost-effectiveness, making it suitable for routine use in pediatric dermatology. Thus, skin ultrasound is an emerging diagnostic tool that enhances the clinical evaluation of atopic dermatitis in children, offering a more comprehensive understanding of disease dynamics. It holds promise for improving the accuracy of diagnosis, monitoring treatment efficacy, and predicting long-term outcomes in pediatric AD patients.

Keywords: atopic dermatitis, children, skin, ultrasound, diagnostics, pediatric dermatology

Relevance. Atopic dermatitis (AD) is a chronic inflammatory skin condition commonly seen in children. Accurate and non-invasive diagnostic methods are essential for assessing the severity and monitoring the treatment of AD. High-frequency ultrasound (HFUS) has emerged as a valuable tool in this context.

Despite the successes achieved in the diagnosis and treatment of atopic dermatitis, many aspects of this problem remain controversial, since it is impossible to avoid subjectivity in assessing skin manifestations and reactions to therapy [2, 3, 4, 9, 24]. Ultrasound examination of the skin may be a promising method [2, 4, 15, 24].

Deeper layers of the skin allow you to visualize ultrasound of the skin, which is based on the principle of scanning tissues with ultrasound in pulse-echo mode [1, 4,]. Ultrasonic waves are

AMERICAN ACADEMIC PUBLISHER

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ISSN NUMBER: 2692 - 5206 Volume 6. No 02. February ,2026

mechanical vibrations, and therefore images obtained using ultrasound are different from optical ones [1, 4, 22].

High-frequency ultrasound can detect a characteristic hypoechoic band below the echo entry, which is indicative of skin inflammation in atopic dermatitis. This feature can be used to assess the severity of the condition [19, 20, 21].

The presence and thickness of the subepidermal low-echogenic band (SLEB) correlate with the severity of atopic dermatitis. This measurement can be used to monitor the response to treatment, with reductions in SLEB thickness indicating improvement [18, 20].

Ultrasound examination provides a non-invasive and objective method to evaluate skin morphology and structure, which is crucial for diagnosing and monitoring atopic dermatitis in children. It complements traditional clinical assessments and enhances the reliability of diagnostic data [20, 21].

Recent advancements include the development of automated segmentation methods for skin layers using deep learning approaches. These tools improve the accuracy and efficiency of ultrasound-based assessments, making them more practical for clinical use [18, 19].

Ultrasound can be used to monitor the effectiveness of treatments such as dupilumab in children with moderate-to-severe atopic dermatitis. Changes in SLEB thickness, epidermal thickness, and vascular signals can serve as objective parameters for evaluating treatment response [20].

High-frequency ultrasound is a valuable tool for the diagnostic assessment of atopic dermatitis in children. It provides a non-invasive, objective, and reliable method to evaluate skin inflammation and monitor treatment efficacy. The presence and thickness of the subepidermal low-echogenic band (SLEB) are key indicators of disease severity and response to therapy. Advances in automated analysis tools further enhance the practicality and accuracy of ultrasound examinations in clinical settings.

The purpose of the study. To analyze the scientific literature in international scientific databases and search engines on the role of skin ultrasound in the diagnostic assessment of skin condition in children with atopic dermatitis.

Materials and methods. The analysis of scientific publications – theses, articles and dissertations in international scientific databases and scientific electronic libraries e-Library, CyberLeninka, Pubmed, Scopus, Cochrane Library, Web of Science, Elsevier, Mbase, including available scientific works in Russian literature over the past 15 years.

Results. Ultrasound examination (ultrasound) found application in the field of dermatology about 30 years ago. In 1979, H. Alexander and D. Miller for the first time assessed the thickness of the skin in a non-invasive way using echography. In the 80s and 90s of the twentieth century, high-frequency sensors were already used in the study of skin formations. The first available ultrasound scanner for skin examination DUB20 was released in 1986 by the German company Taberna Pro Medicum. Until that time, the resolution of ultrasound equipment could not provide visualization of skin structures, and therefore skin echography remained uninformative [14, 23, 25, 27].

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With the development of ultrasound diagnostic equipment and the development of high-frequency sensors, it became possible to visualize skin layers and use this method in the field of dermatology. Modern medical technology makes it possible to study the skin in normal and pathological conditions, using 3D image modeling technologies, color and energy Doppler mapping and sonoelastography, which are currently experimental [23, 31].

The most popular noninvasive optical diagnostic methods used in dermatology include confocal laser microscopy, optical coherence tomography, and dermatoscopy. Among the advantages of these methods, high resolution and the ability to obtain detailed information about the morphological parameters of the skin are indicated. However, the available scanning depth for optical examination is limited to the surface layers of the skin in 1-2 mm. For a pathomorphological examination, which usually confirms a particular diagnosis, the material is taken using a biopsy, which, in addition to the time required to obtain a result, is often associated with strict requirements for compliance with aesthetic standards. Ultrasound is a non—invasive method that allows to assess the condition of the skin and pancreas in vivo and in "real time" mode. Thus, echography can serve as a "link" between physical examination and histological examination [14, 25].

According to the scientific literature, using echography, it is possible to measure the depth and thickness of neoplasm germination (in basal cell carcinoma, nodular and superficially spreading melanoma), perform a preoperative assessment to select surgical tactics, and carry out postoperative control [17, 26, 32]. The capabilities of the method make it possible to monitor the condition of the skin in the treatment of a number of dermatoses (psoriasis, chronic eczema, atopic dermatitis, acne, collagenosis), dynamically evaluate the effectiveness of cosmetic procedures (mesotherapy, peeling, fillers, botulinum toxin) [1, 23, 28, 31, 33]. With the help of ultrasound, it is possible to identify signs of skin aging, exposure to local and systemic drugs (corticosteroids, estradiol) on the skin, as well as visualization of X-ray negative foreign bodies and diagnosis of pathological processes such as abscess and cellulite of the pancreas [16, 25, 29, 31].

In traditional echography, convexic sensors with a scanning frequency of 3-10 MHz are used in general practice, providing a penetration depth of 100-150 mm. To study the skin, linear sensors with a frequency range of 12-17 MHz have the greatest diagnostic information, which provide good resolution in the near field [11, 14, 23, 27].

At a scanning frequency of 20 MHz, small structures of the epidermis and dermis are clearly distinguishable, and the penetrating ability of ultrasound under these conditions is 6-7 mm. At frequencies in the range of 50-100 MHz, when the depth of penetration of ultrasonic waves is minimal (0.15–3 mm), and the image resolution is higher, a detailed analysis of the structures of the epidermis, basement membrane, and upper layers of the dermis is possible [23, 27].

The choice of a sensor with the appropriate frequency depends on the depth of the location and size of the formation. A. Mandava et al. (2013) note that skin examination should begin by choosing a sensor of a lower frequency, since it provides a large area of visualization. In the process of research, it is advisable to increase the frequency range to obtain the maximum clear image of the object under study. When conducting skin echography, it is recommended to apply an abundant amount of gel to the area under study, which minimizes artifacts and avoids excessive compression, since this can lead to a change in skin tension and an erroneous

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interpretation of the thickness and echogenicity of structures, as well as cause the collapse of small vessels. During the study, the area of the affected skin should be compared with the unchanged skin of the opposite side or adjacent area [8, 25].

The echographic picture of the skin layers depends on the content of its main components. The echogenicity of the epidermis is due to the presence of keratin in it, the dermis — collagen, and the pancreas — the number of fat lobules and connective tissue fibers. The epidermis of healthy skin looks like a homogeneous hyperechoic line (input echo) on the entire surface of the body, with the exception of the palmar and plantar areas. In these areas, the epidermis is visualized as a two-layered hyperechoic line. The input echo consists of echoes from the stratum corneum of the epidermis, its underlying layers and the epidermal-dermal junction. Its thickness varies depending on the anatomical area, age, gender and individual characteristics of the skin.

The dermis, being displayed less brightly than the input echo, has a heterogeneous echogenicity due to the presence of structures with different acoustic density. Areas of the dermis with higher echogenicity are caused by the presence of intertwining bundles of collagen fibers that strongly reflect ultrasonic waves. Small hypoechoic areas are also visualized in the dermis, which correspond to sweat and sebaceous glands and their ducts, hair follicles and blood vessels. Their number and location may vary depending on the area of the body. The pancreas is visualized as a wide hypoechoic band pierced by thin linear hyperechoic connective tissue partitions [8, 25, 27, 31].

It is believed that the unchanged epidermis has a thickness of 0.03–1 mm, the dermis is 0.5—4 mm, and the pancreas is on average 5-20 mm, but for the doctor it is not the absolute thickness of the studied specific skin area that is important, but its difference from the symmetrical area of healthy skin of this patient [8, 25].

With the help of ultrasound, it is possible to study skin changes in inflammatory processes. According to a number of authors, ultrasound imaging of psoriatic plaques shows an increase in echogenicity and a thickening of the input echo, which is associated with the presence of hyperkeratosis. Focal hypoechoic zones perpendicular to the input echo correspond to air bubbles between the scales. In the upper part of the dermis, researchers describe a band of reduced echogenicity characteristic of inflammatory lymphohistiocytic infiltration and edema of the upper part of the papillary layer. Such a subepidermal hypoechoic band, especially pronounced in the acute period of the disease, is characteristic not only of psoriasis, but also of other inflammatory skin diseases (atopic dermatitis, eczema). It is associated with the accumulation of inflammatory mediators in the intercellular space, which diffusely reduce the echogenicity of the dermis. Dilated capillaries of the dermis are displayed by small focal hypoechoic inclusions. In the area of psoriatic plaques with Color Doppler Coding (mapping) and Energy Doppler Mapping (EDM), a diffuse increase in blood flow is recorded. According to the literature, in these areas, the thickness of the skin increases by an average of 55% compared to healthy skin, and ultrasound can reliably detect these skin changes [8, 25, 27, 31].

A. Polanska et al. (2013) in the study of echograms of skin areas affected by atopic dermatitis, the presence of a wide hypoechoic band below the input echo and a diffuse decrease in echogenicity of the dermis were noted. A high correlation was found between the degree of this decrease and the severity of the inflammatory process. After the therapy, a decrease in the thickness of the subepidermal hypoechoic band and an overall increase in skin echogenicity were

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determined. Based on the monitoring of these changes in inflammatory skin processes using ultrasound, it is possible to judge the phase of the disease and the effectiveness of the treatment [27, 28].

Yu.A. Krakhaleva (2018), when performing ultrasound of the skin of patients with atopic dermatitis in the lesions and in the adjacent area of healthy skin, found that in children with ATD in the lesions, an increase in epidermal thickness, thickening and a decrease in echogenicity of the dermis was observed at SCORAD > 15. Observations also showed that at SCORAD > 40, the echogenicity of the epidermis was reduced. In addition, it was found that in 78% of cases in children with AtD, the epidermis had uneven contours, and in 76%, a subepidermal hypoechoic band was observed. In children with AtD, a subepidermal hypoechoic band was detected in 78% of healthy skin, and in 59% the epidermis had uneven contours. During treatment in patients with AtD, the greatest changes were observed from the side of the subepidermal hypoechoic band — a decrease in its thickness by 1.7 times and an increase in echo density by 2.7 times [6].

According to O.E. Fedortsiv and co-authors (2016), echography in the acute period in all children determines a distinct thickening of the skin, mainly due to the dermis, a violation of the clarity of the skin layers, an increase in echogenicity of the epidermis, a decrease in echogenicity of the dermis and heterogeneity of its structure, the appearance of a characteristic hypoechoic strip between the epidermis and the dermis, which can be considered as a marker process activity. The boundary between the dermis and the subcutaneous layer was less distinct than in practically healthy children. In children with lichenification, an uneven surface of the epidermis was observed. The epidermis and dermis were separated by a thin normally invisible hypo-echogenic strip. The overall thickness of the skin is increased due to both layers. Dopplerography detected intradermal arterial and increased subcutaneous arterial and venous blood flow.

In the subacute period of blood pressure, compared with the acute process, there was a moderate increase in echogenicity of the dermis, the intermediate hypoechoic strip between the epidermis and the dermis was not visualized, but the ultrasound characteristics of the epidermis remained preliminary. Such dynamics in the echogenicity of the skin layers reduced the clarity of their differentiation. The total thickness of the skin, as well as its individual layers, significantly decreased compared to the acute period. According to Dopplerography, intradermal arterial blood flow was not determined, but intradermal venous blood flow was recorded.

In the period of AtD remission, the ultrasound picture of the skin corresponded to that in the control group, and its thickness was smaller compared to the periods of exacerbation and subsiding of the process, but larger compared to the skin of practically healthy children. During Dopplerography, blood flow during remission, both in the skin and in the subcutaneous layer, was not recorded, which corresponded to the results obtained in practically healthy children [13].

The echographic picture of healthy skin was as follows: the surface of the epidermis was smooth, the entire thickness of the epidermis was visualized along the scanning front, the thickness of the epidermis was uniform, from 0.20 to 0.60 mm, the echo signal from the surface into the dermis was not interrupted, the echogenicity of the epidermis was homogeneous (from 127.00 to 129.00 units), the inner contour of the epidermis was smooth, there was a clear separation from the dermis. The epidermis had the appearance of a narrow hyperechoic strip with a smooth outer contour. The thickness of the unchanged epidermis depended on the study area, the age of the patient and averaged (0.40±0.02) mm for the control group, the average

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echogenicity was (128.00±0.12) units. According to the literature, this nic display varies from 0.03 to 1.00 millimeters. The thickness of the dermis is uniform from 0.40 to 0.90 mm, the average echogenicity of the dermis is from 42.00 to 46.00 units, the echogenicity of the upper layers of the dermis is 21.00 units, the lower layers are 55.00 units, the separation of the dermis from subcutaneous adipose tissue was clear, the contour is inter-level. The dermis was visualized as a strip of medium or reduced echogenicity, depending on the study area, homogeneous echostructure, thickness (0.56±0.02) mm on average in the group, the average echogenicity of the dermis was (44.00±0.23) units. According to various literature sources, the thickness of the dermis of unchanged skin ranges from 0.50 to 4.00 millimeters. Vessels in the dermis were by no means detected, which can be explained by their small diameter and low blood circulation rate. In the areas of subcutaneous fat adjacent to the dermis, dopplerometry revealed small arterial and venous vessels in 12 (30.00%) of the examined patients. The echogenicity of subcutaneous fat ranged from 2.00 to 6.00 units, the average echogenicity was (3.00±0.15) units. The thickness of the skin depended on the anatomical area and the age of the children. The severity of ultrasound skin changes in children with blood pressure was determined by the period of the disease and the localization of the process [12].

I.V. Dvoryakovsky and co-authors (2009) used ultrasound to assess the condition of the skin in atopic dermatitis in various periods of the disease [2]. At the same time, skin assessment was carried out in areas characterized by the maximum manifestations of atopic dermatitis: elbow and popliteal folds, the area of wrist and ankle joints, on the face in the cheek area with determination of the total thickness of the skin, the thickness of the epidermis and dermis, the degree of differentiation of these layers, their echogenicity. Dopplerography (color Doppler mapping, energy Doppler examination, pulse wave Dopplerography) assessed the vascularization of the skin and subcutaneous layer. Thus, according to the results of the study, it was found that in all children of the control group, regardless of age, the skin structure during ultrasound examination was represented by several layers: the first hyperechoic surface layer histologically corresponded to the epidermis, the second hypoechoic layer to the papillary layer of the dermis and the third thin hyperechoic layer separating the papillary layer from the subcutaneous layer to the reticular layer of the dermis. A hypoechoic and rather heterogeneous subcutaneous layer was visualized immediately under the skin.

Echography in the acute period in all children revealed an increase in echogenicity of the epidermis, a decrease in echogenicity of the dermis and heterogeneity of its structure. The boundary between the dermis and the subcutaneous layer was less distinct than in the children of the control group. In children with lichenification, the surface of the epidermis was uneven. The epidermis and dermis were separated by a thin normally invisible hypoechoic strip. The overall thickness of the skin is increased due to both layers. Dopplerography detected intradermal arterial blood flow in 70% of children in this group, and subcutaneous arterial and venous blood flow in 96% of children.

In the subacute period of atopic dermatitis, compared with the acute process, there was a moderate increase in echogenicity of the dermis, the intermediate hypoechoic strip between the epidermis and the dermis was not visualized, but the ultrasound characteristics of the epidermis remained the same. Such dynamics in the echogenicity of the skin layers reduced the clarity of their differentiation. The total thickness of the skin, as well as its individual layers, significantly decreased compared to the acute period. According to Dopplerography data, intradermal arterial

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blood flow was not determined in the subacute period. Intradermal venous blood flow was recorded in 63% of children.

During the period of remission of atopic dermatitis, the ultrasound picture of the skin corresponded to that in the control group, while its thickness was smaller compared to the periods of exacerbation and subsiding of the process, but larger compared to the control group. During Dopplerography, blood flow during remission in both the skin and subcutaneous layer was not recorded, which corresponded to the results obtained in the control group [2].

The degree of severity of ultrasonic skin changes was determined by the period of the disease and the localization of the process. The selectivity of skin manifestations, in turn, depended on the thickness of the skin, which is minimal in the area of the elbow bends, especially in children of the younger age group (3-5 years).

Thickening of the skin due to the epidermis and dermis and an increase in the echogenicity of the epidermis in children in the acute period of atopic dermatitis may be associated with hyper and parakeratosis, acanthosis, focal spongiosis [10], which also cause tissue heterogeneity against the background of edema. The origin of the hypoechoic strip between the epidermis and the dermis, localized at the location of the main membrane, may be associated with edema and inflammatory infiltration in the uppermost parts of the dermis [10]. These changes contributed to a better visual differentiation of the skin layers, which directly depended on the severity of the skin process. Edema, apparently, was the reason for the decrease in echogenicity of the dermis and the alignment of echogenicity between the dermis and the subcutaneous layer.

The registration of intradermal and subcutaneous blood flow, observed in children only during periods of exacerbation and subsiding, suggests an increase in blood flow to the site of inflammation, which is manifested by hyperemia. With the greatest frequency, blood flow was detected in the places of the most pronounced changes. An increase in intradermal blood flow occurs, apparently, in the superficial plexuses of skin vessels located in the subcutaneous layer, and subcutaneous blood flow occurs in vessels belonging to the deep plexus, which is localized at the border with subcutaneous tissue [10].

Ultrasonic changes observed in the skin as the pathological process subsided and went into remission were associated with a decrease in inflammation, which was expressed by a decrease in skin thickness, an increase in echogenicity of the dermis, the disappearance of the hypoechoic strip between the epidermis and the dermis, the absence of arterial and the appearance of venous intradermal blood flow.

Positive dynamics according to clinical data during remission was observed in 85% of children. However, according to ultrasound examination, the thickness of the skin in most of the studied areas significantly exceeded normal values, although it decreased compared to the subacute period. This was especially pronounced in young children. Complete normalization of the skin condition according to ultrasound was observed only in 9% of children, mostly older. In 6% of children (aged 12-17 years), the thickness of the skin during remission was less than normal, which could be due to its atrophy as a result of significant disease experience (more than 5 years) and prolonged use of local glucocorticosteroids in the places of natural folds most susceptible to atrophy [2].

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Conclusions. Thus, according to ultrasound examination in atopic dermatitis in areas of local inflammation, changes were observed in all layers of the skin, which corresponds to morphological and functional changes in the epidermis and dermis [5]. Thickening and hypoechoicity of the epidermis and dermis were observed in lesions in patients with AtD, which can be considered as ultrasound criteria for the inflammatory process. The subepidermal hypoechoic band reflects the degree of inflammatory edema of the papillary layer of the dermis, changes on its part must be controlled during therapy.

The severity of the changes is facilitated by the physiological features of children's skin: hydrophilicity and lability of the osmotic state of cellular and fibrous elements of the connective tissue of the dermis, increased permeability of the vascular endothelium, a large number and increased activity of tissue basophils located perivascularly [5]. All this is the reason not only for the rapid development of a specific inflammatory process in the skin, but also for the rapid absorption of drugs used for external therapy, including topical steroids, the frequent uncontrolled use of which can lead to the development of local and systemic adverse reactions [30].

In this regard, it is important to objectively assess the degree of inflammation and the activity of the pathological process. The most accurate criterion for the presence (absence) of inflammation may be the state of cutaneous blood flow according to Dopplerography, since it is recorded only in the acute and subacute periods of atopic dermatitis. Thus, in the absence of cutaneous blood flow, it is possible to cancel local glucocorticoid therapy, that is, Dopplerography can be used as an additional criterion for evaluating the effectiveness and duration of treatment.

Echography is a method of choice in the diagnosis of pathological skin conditions, since most diseases of this localization have a characteristic morphological soft-tissue substrate. Ultrasound imaging allows you to simultaneously obtain high-quality high-resolution gray scale image, color reflection of vascularization and hemodynamic information in real time. With the help of ultrasound scanning, it is possible to obtain detailed information about the anatomical and physiological features of the structure of both the studied disease zone and the surrounding tissues. The advantages of using this method include its non-invasiveness, as well as the absence of radiation exposure. However, this method requires specialized equipment and an experienced diagnostician, who must possess not only ultrasound diagnostic skills, but also basic knowledge in the field of dermatology in order to be able to compare the received echographic data with the clinical picture of the disease. Thus, ultrasound is recognized as a promising highly informative non-invasive method for skin examination.

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