Expression of CD1d in human scalp skin and hair follicles: hair cycle related alterations

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Background: CD1d belongs to a family of antigen presenting molecules that are structurally and distantly related to the classic major histocompatibility complex class I (MHC I) proteins. However, unlike MHC I molecules, which bind protein antigens, CD1d binds to lipid and glycolipid antigens. CD1d is expressed by cells of lymphoid and myeloid origin, and by cells outside of the lymphoid and myeloid lineages, such as human keratinocytes of psoriatic skin.

Aims: To investigate whether CD1d is also expressed in sun exposed skin and in the immunoprivileged anagen hair follicle.

Materials/Methods: CD1d immunoreactivity was studied in human scalp skin and hair follicles of healthy women in situ by immunofluorescent and light microscopic immunohistology. Skin biopsies were obtained from normal human scalp containing mainly anagen VI hair follicles from women (age, 53–57 years) undergoing elective plastic surgery.

Results: CD1d showed strong immunostaining in human scalp skin epidermis, pilosebaceous units, and eccrine glands. In the epidermis, CD1d was strongly expressed by basal and granular keratinocytes. In hair follicles, CD1d was expressed in the epithelial compartment and showed hair cycle related alterations, with an increase in the anagen and a reduction in the catagen and telogen phases.

Conclusions: These results suggest that CD1d plays a role in human scalp skin immunology and protection against lipid antigen rich infectious microbes. They also raise the question of whether keratinocytes of the immunoprivileged anagen hair follicle can present lipid antigens to natural killer T cells. These data could help provide new strategies for the manipulation of hair related disorders.

CD1d is a member of the CD1 family of transmembrane glycoproteins, which form a third lineage of antigen presenting molecules distantly related to the classic major histocompatibility complex (MHC) molecules of the immune system.1,2 However, unlike the first and second lineages of antigen presenting molecules (the MHC class I and class II molecules), CD1 molecules have evolved to bind lipids and glycolipids.3,4 CD1 family molecules are closely related to MHC class Ia and Ib proteins by sequence homology, domain organisation (x1, x2, x3, and β2 microglobulin), and association with β2 microglobulin, rather than to class II molecules.1 In contrast to MHC class I molecules, which are polymorphic, CD1 molecules are not polymorphic5 and are encoded by linked genes outside the MHC complex; the gene for CD1d is located on chromosome 1 in humans.1,5 The CD1 family is divided into two groups by sequence homology: group I, which consists of the CD1a, CD1b, and CD1c isotypes; and group II, which includes CD1d. Only the group II CD1d isotypes are preserved in humans, mice, rats, rabbits, and monkeys.6 Sequence similarity is substantially higher for the same isotype from different species than for different isotypes within the same species,7 suggesting that each group of CD1 molecules could have a different function.8

“CD1d plays a crucial role in several immunoregulatory functions within the human and mammalian body.”

CD1d is essential for the development and activation of a subset of T cells known as natural killer T (NK-T) cells, which are characterised by the expression of receptors used by NK cells8 and invariant Vα2-Jα T cell receptors, such as Vα24JαQ in humans and Vα14Jα281 in mice.9 NK-T cells recognise self or non-self glycolipids presented by the CD1d molecule and respond by secretion of cytokines, most notably interferon γ and interleukin 4.2,10 The synthetic glycolipid molecule α galactosylceramide stimulates human and mouse NK-T cells in a CD1d restricted manner.9,10 Therefore, via the production of cytokines secreted by NK-T cells, CD1d plays a crucial role in several immunoregulatory functions within the human and mammalian body, including protection against autoimmune diseases, microbial infection, and cancer. In mice, it was shown that CD1d promotes ultraviolet induced carcinogenesis by inhibiting apoptosis and thereby preventing the elimination of potentially malignant keratinocytes and fibroblasts.9,10,11

Recently, CD1d expression and NK-T cells were demonstrated in the epidermis of acute and chronic psoriatic plaques.12,13 The mammalian hair follicle undergoes lifelong transformations from a resting stage (telogen) to a growth stage, characterised by rapid cell proliferation and keratinocyte differentiation with production of pigmented hair fibre (anagen), and finally to an apoptosis induced and stress associated involution stage (catagen), which leads again into telogen.14 The hair follicle is an immunoprivileged organ, mainly characterised by MHC class I negativity and an immunosuppressive cytokine milieu. Recent studies showed that human hair follicle keratinocytes of sun protected skin express CD1d.15,16 Whether CD1d is expressed in human scalp hair follicles and whether its expression undergoes hair cycle related changes is still unclear. Therefore, our current study aims to explore the expression of CD1d in human scalp skin and hair follicles at different cycle stages.

Abbreviations: IRS, inner root sheath; MHC, major histocompatibility complex; NK, natural killer; ORS, outer root sheath; TBS, Tris buffered saline; TSA, tyramide signal amplification
CD1d in human scalp skin and hair follicles

MATERIALS AND METHODS

Skin samples

Skin biopsies from healthy human scalp containing mainly anagen VI hair follicles were obtained after informed consent from women (age, 53–57 years) undergoing elective plastic (cosmetic) surgery. After surgery, samples were maintained in Williams E medium (Biochrom KG Seromed, Berlin, Germany) for transportation at 4°C for up to 24 hours. Skin specimens used for cryosections were frozen abruptly in liquid nitrogen and stored at −80°C until use. Before immunostaining, samples were embedded and processed for longitudinal cryosections (8 μm). Sections were dried, fixed in cold acetone (−20°C), and stored at −20°C until used for immunohistochemistry.

Immunohistochemistry

Cryosections of normal human scalp skin were immunostained using mouse monoclonal IgG1 antihuman CD1d (BioSource International, Camarillo, California, USA). Two labelling techniques were performed to visualise antigen–antibody complexes: avidin–biotin complex labelling (Vector Laboratories, Burlingame, California, USA) and the highly sensitive immunofluorescent tyramide signal amplification (TSA) labelling method (PerkinElmer Life Science, Boston, Massachusetts, USA). For the avidin–biotin complex labelling method, cryosections were washed in Tris buffered saline (TBS; 0.05M, pH 7.6) and preincubated with avidin–biotin blocking solution (Vector Laboratories), followed by incubation with protein blocking agent (Immunotech, Krefeld, Germany) to prevent non-specific binding. Sections were then incubated with the primary antibody diluted in TBS (1/200) for 30 minutes at room temperature. Thereafter, sections were incubated with streptavidin horseradish peroxidase (1/50 in blocking buffer) for 30 minutes at room temperature. Finally, sections were counterstained with streptavidin peroxidase (1/50 in blocking buffer) for 30 minutes at room temperature. The walls of the blood vessels served as positive controls (fig 1F). Negative controls

Additional sections, running in parallel but with omission of the primary antibody, served as negative controls (fig 2J).

RESULTS

The positive and negative controls showed positive and negative reactivity, respectively, validating our immunostaining results.

CD1d is prominently expressed in the epidermis, some dermal elements, hypodermis, the eccrine sweat glands, and sebaceous glands

In the epidermis, immunoreactivity for CD1d was detected predominantly in the keratinocytes of the basal layer and three...
to four layers of the stratum granulosum directly beneath the stratum corneum (fig 1A; table 1). CD1d immunopositivity was also seen in the stratum spinosum, but with weaker intensity than in the basal and granular layers (fig 1A). In the dermis, weak CD1d immunoreactivity was seen in some dendritic cells of the papillary dermis adjacent to the epidermal basal layer (fig 1A) and in other dermal cell types around hair follicles (fig 2F) and blood vessels (fig 1F). Prominent CD1d expression was found in blood vessel walls and endothelial elements (fig 1F). In the hypodermis, CD1d immunostaining was intense in adipose tissue cells surrounding the anagen hair follicle bulb (fig 2G). In the eccrine sweat glands, strong CD1d immunostaining was found in all cells, with expression on the cell membrane and throughout the cytoplasm, and staining was stronger in the sweat ducts (fig 1E). In the sebaceous glands, strong CD1d immunostaining was detected in the peripheral sebocytes and moderate staining was seen in the central sebocytes (fig 1B).

**CD1d is expressed in human scalp hair follicles and shows hair cycle dependent alterations**

In anagen VI hair follicles (fig 2A–G; table 2), CD1d immunoreactivity was prominently detected in the outer root sheath (ORS), in the inner root sheath (IRS), and in the differentiating corteocytes. Weak, if any, CD1d expression was found in the hair matrix cells and the dermal papilla (fig 2D). Prominent CD1d expression was found in the hair matrix cells and the dermal papilla (fig 2D). In the IRS, CD1d was found in almost all follicle regions, including the proximal hair bulb region, the central region, and the distal region, with different staining

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**Table 1** Immunoreactivity and distribution of CD1d in human skin

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<th>Staining distribution</th>
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BV, blood vessels; DS, dermal stroma; HF, hair follicle; SB, stratum basale; SBG, sebaceous gland; SC, stratum corneum; SG, stratum granulosum; SS, stratum spinosum; SWG, sweat gland; +, weak expression; ++, strong expression; ++++, very strong expression.
of potentially malignant keratinocytes and fibroblasts. In mice, CD1d was also found to mediate contact sensitivity by activating B1 cells to produce IgM, which activates complement to promote T cell passage into the tissues. In psoriasis, a severe autoimmune skin disease, CD1d is overexpressed by keratinocytes, suggesting that it plays a role in regulating and mediating the pathogenesis of cutaneous autoimmune diseases.

"The most intriguing finding of our current study is the strong expression of CD1d by the pilosebaceous unit, which is the site of the common multifactorial skin disease of young adults, acne."

Our current study revealed that CD1d is prominently expressed in the epithelial compartment of anagen VI hair follicles, mainly in ORS and IRS keratinocytes, melanocytes, and some corteocytes. This could mean that CD1d plays an important role in supporting the anagen phase by inhibiting apoptosis, and is thus involved in regulating the human hair cycle. Several studies have shown that keratinocyte proliferation and differentiation are induced by lipids. N-Acylated forms of sphingolipids, such as ceramides, have been shown to promote keratinocyte differentiation, and sphingosine and sphingosylphosphorylcholine promote keratinocyte proliferation. The high amounts of CD1d produced during anagen might bind lipid molecules and induce keratinocyte proliferation and differentiation, thus supporting anagen. This view is supported by the finding that CD1d deficient mice have severe skin disorders, manifested as hair loss and scar formation. Alternatively, as an antigen presenting molecule, CD1d binds available glycolipid antigens and activates NK-T cells, so that it may play a role in immunity and protection of the hair follicle. However, this raises the question of whether the proximal anagen hair follicle can mount an immune response; it is thought to be an immune privileged organ because its compartments do not express the classic MHC class I antigen presenting molecules and it is characterised by an immunosuppressive cytokine milieu. Previous studies have shown that human and murine proximal hair follicles are negative for peptide antigen presenting cells, but the role of lipid and glycolipid antigen presenting cells in these pilosebaceous units is unclear. Although our current study revealed strong expression of CD1d in the proximal anagen hair follicle, the coexistence of NK-T cells within anagen hair follicle compartments was not investigated. This should be investigated in future studies. However, the presence of a few NK-T cells around the anagen hair follicle may support our results and indicate a role for anagen hair follicle keratinocytes in lipid antigen presentation to NK-T cells (R Paus, personal communication, 2002).

Our present study also revealed strong expression of CD1d in the eccrine sweat gland, suggesting a role for CD1d in the normal functioning of the sweat gland and/or that sweat gland cells play a role in the human scalp skin immune system, by presenting lipid and glycolipid molecules to NK-T cells. Lampert et al reported the expression of MHC class II antigen presenting molecules in the lining cells of the sweat gland, more evidence of a role for the sweat gland in the immune system of the skin; however, these authors also suggested that MHC class II molecules might have a role in the development and the normal function of adult sweat gland cells. Our present results are supported by those of Bonish et al, who showed the expression of CD1d in sweat glands of skin areas other than the scalp.

The most intriguing finding of our current study is the strong expression of CD1d by the pilosebaceous unit, which is the site of the common multifactorial skin disease of young adults, acne.
The expression pattern of CD1d in human scalp skin suggests that it plays an important role in the immunology of this tissue and in the protection against lipid antigen rich infectious microbes. These results also suggest that keratinocytes of the immunoprivileged anagen hair follicle can present lipid antigens to natural killer T cells. These data could help provide new strategies for the manipulation of hair related disorders, such as alopecia.

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REFERENCES
Case 2. Multicystic tumour with thickened septa. 

In particular, no central scar was seen. Therefore, these tumours were classified as suspected cystic tumours, Bosniak’s class 3. Only microscopic examination can identify the characteristic oncocytic cells covering the tumour septa. However, a minor component of usual oncocytoma is also often seen.

In the first case, focal invasion of the perirenal adipose tissue was present. This unusual feature is seen in less than 10% of oncocytomas in large series, and has no effect on the prognosis. Oncocytomas may present limited central microcystic degeneration but a prominent multicystic presentation is very unusual. Only isolated cases have been reported in the English literature.

The diagnosis cannot be made radiologically. In the literature, one case resembled a haemorrhagic renal cyst on imaging. In a recent series of 28 cases of atypical renal cystic tumours evaluated by imaging guided biopsy, one case of cystic oncocytoma was diagnosed.

The prognosis of this variant is excellent; metastasis has not been reported. The clinical course appears to be very similar to that of usual oncocytoma and these tumours may be managed by partial nephrectomy.

References