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

M A Adley, H A Assaf, M Hussein

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. 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. CD1 family molecules are closely 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.

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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 cells and invariant Vα2-Jα2 T cell receptors, such as Vα24JαQ in humans and Vα24Jαα281 in mice. 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. The synthetic glycolipid molecule α-galactosylceramide stimulates human and mouse NK-T cells in a CD1d restricted manner. 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.

Recently, CD1d expression and NK-T cells were demonstrated in the epidermis of acute and chronic psoriatic plaques. 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. 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. 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
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, tetramethylrhodamine–isothiocyanate–peroxidase (1/50 in blocking buffer) for 30 minutes at room temperature. For the TSA labelling technique, cryosections were washed in Tris/acid/Tween buffer (pH 7.5), followed by washing in 3% hydrogen peroxide (H2O2). Sections were then incubated with a lower concentration of the primary antibody diluted in Tris/acid blocking buffer (pH 7.2; 1/1000 dilution) overnight at 4°C. Next, sections were washed in Tris/acid/Tween and incubated with Cy3 conjugated F(ab)2 fragments of goat antimouse IgG secondary antibody (Jackson ImmunoResearch Laboratories) diluted in blocking buffer (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, tetramethylrhodamine–isothiocyanate–tyramide amplification reagent was added (1/50 dilution in amplification diluent provided with the kit) for 30 minutes at room temperature, followed by counterstaining with 4',6-diamidino-2-phenylindole and mounting in levamisole (Dako Corporation, Carpenteria, California, USA). The TSA signals were visualised under a fluorescence microscope (Carl Zeiss, Jena, Germany).

Positive controls
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 prominently in the keratinocytes of the basal layer and three
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,G,K). In the ORS, CD1d was found in almost all follicle regions, including the proximal hair bulb region, the central region, and the distal region, with different staining intensity 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,D).

Table 1 Immunoreactivity and distribution of CD1d in human skin

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<th>Staining distribution</th>
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<tr>
<td>SB</td>
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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.
Table 2  Immunoreactivity and distribution of CD1d within hair follicle compartments and changes throughout hair cycle stages

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<th>Anagen VI</th>
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<tr>
<td>ORS (+++), IRS (+++), DP (+), ES (+), prekeratinocyte (+++), HS (+), corneocytes (+)</td>
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DP, dermal papilla; ES, epithelial strand; HS, hair shaft; IRS, inner root sheath; ORS, outer root sheath; +, weak expression; ++, strong expression; +++: very strong expression.

inhibiting apoptosis and thereby preventing the elimination 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.

**Table 2: Immunoreactivity and distribution of CD1d**

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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.

**DISCUSSION**

CD1d plays a crucial role in mammalian skin biology as an antigen presenting molecule that binds lipid and glycolipid antigens. Our current study revealed that CD1d is expressed by epidermal keratinocytes of normal human scalp skin and this is supported by Bonish et al. who reported the expression of CD1d by keratinocytes of normal human skin from regions of the body other than the scalp. They found a high expression rate in the superficial keratinocytes close to the lipid rich stratum corneum. We also found intense CD1d expression in other epidermal layers including basal keratinocytes. This implies the involvement of basal and suprabasal keratinocytes in binding glycolipid antigens to activate NK-T cells to secrete interferon γ, and that these cells play a role in the immunity of human scalp skin. CD1d has also been shown to play a regulatory role in inflammatory skin diseases. CD1d deficient MRL-lpr/lpr mice have more frequent and more severe skin disease than their wild-type littersmates, with increased local infiltration by mast cells, lymphocytes, and dendritic cells, including Langerhans cells. NK-T cells, which are activated by CD1d stimulation, were shown to mediate cutaneous inflammatory reactions to fly larvac, suggesting a role for CD1d in protection against fly larva infestation. There is strong evidence that CD1d is a crucial regulator of ultraviolet induced carcinogenesis, by inhibiting apoptosis and thereby preventing the elimination 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.

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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.
adults, acne. This disease is caused by: (a) abnormal ductal keratinisation as a result of ductal keratinocyte hyperproliferation induced by the modified lipid composition of the sebum; (b) increased sebum production leading to seborrhea; and (c) abnormalities in microbial flora. The pilosebaceous unit has two peculiar aspects, manifested as constant hosting of Propionibacterium acnes and its richness in lipids. Acne lesions develop by two mechanisms—recognition of the microbial pathogens by Toll-like receptors and presentation of abnormal lipids by CD1d molecules. This results in the activation of NK-T cells that further activate both the cells of the innate immune system and those of the adaptive immune system, thus forming a link between innate and adaptive immunity. In this context, CD1d, which we found to be highly expressed by cells of the pilosebaceous unit, plays a crucial role in the pathogenesis of acne by presenting foreign lipid antigens (many pathogens possess lipid antigens) and self modified lipid molecules to NK-T cells. In conclusion, the strong expression of CD1d in healthy human scalp skin and skin appendages suggests that it plays a crucial role in scalp skin biology. This may be by regulating normal functions and/or by its involvement in skin immunology. Thus, CD1d plays a role in protection against infectious diseases caused by microbes rich in lipid antigens. The increase in CD1d expression within the hair follicle during anagen and its decrease during the catagen and telogen phases suggests that it is involved in anagen induction or elongation and possibly plays a role in regulating catagen induced and related hair disorders such as alopecia. Alternatively, the strong expression of CD1d in the proximal part of the anagen hair follicle raises the question of whether keratinocytes from an immunoprivileged organ can respond to both foreign lipid antigens and self modified lipid molecules and present them to NK-T cells.

ACKNOWLEDGEMENTS
This research was carried out in the Department of Dermatology and Venerology, Universit Hospital of Hamburg-Eppendorf, Hamburg University and supported by the DFG (Deutsche Forschungsgemeinschaft), Germany.

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REFERENCES
A 47 year old woman without relevant antecedents presented with diffuse abdominal pain. A CT scan and MRI studies were performed and showed a small 3.5 cm multilocular cystic tumour in the upper pole of the left kidney. Multiple thickened septa were more easily seen on the MRI than the CT scan. Septa and wall were well enhanced on contrast imaging. A partial nephrectomy was performed, and eight months later the patient is well.

On gross examination, both tumours were predominantly cystic, multilocular, with thickened septa, and with no central scar. Microscopically, septa were covered by cuboidal or columnar eosinophilic cells (figs 2, 3). The cytoplasm was abundant and granular. The nuclei were round with one or several nucleoli. No severe atypia or necrosis was noted. No hobnail cells were found. Mitotic activity was low (less than one mitotic figure/10 high power fields). A small area of classic solid tubulocystic oncocytoma was identified in each case. In the first case, tumour cysts focally invaded the perinephric fat. No vascular invasion was seen. On immunohistochemistry, tumour cells were diffusely positive for epithelial membrane antigen and pancytokeratin and focally positive for cytokeratin 7. Staining for cytokeratin 20, high molecular weight cytokeratin, and CD10 was negative.

Oncocytoma is a renal adenoma that makes up 5–7% of all renal tumours. It is a solid mass that develops in the renal parenchyma with a central fibrous scar. Oncocytoma with prominent macroscopic cystic features is very unusual and should be distinguished from other renal cystic tumours, such as multicellular clear cell carcinoma or cystic nephroma. Preoperatively, in our cases, no distinction was possible by imaging studies; in particular, no central scar was seen. Therefore, these tumours were classified as suspected cystic tumours, Bosniak’s class 3.

References

The Oxford Dictionary of Medical Quotations

Full details of events to be included should be sent to Mike Mair, Editorial Assistant; email: jclinpath@bmgroup.com

Diagnostic Histopathology of Breast Disease
8–12 May 2006, Hammersmith Hospital and Imperial College, London, UK
Further details: Wolfson Conference Centre, Hammersmith Hospital, Du Cane Road, London W12 ONN, UK. (Tel +44 (0)20 8383 3117/3227/3243; Fax +44 (0)20 8383 2428; e-mail wcc@ic.ac.uk)

Practical Pulmonary Pathology
25–28 July 2006, Brompton Hospital, London, UK
Further details: Professor B Corrin, Brompton Hospital, London SW3 6NP, UK. (Tel +44 (0)20 7351 8425; Fax +44 (0)20 7351 8293; e-mail b.corrin@ic.ac.uk)

Diseases and Tumours of the Salivary Glands
21–22 October 2006, Landeskliniken Salzburg, Paracelsus Medical University, Austria
Further details: Dr J Beck-Mannagetta, Maxillofacial Surgery/SALK-PMU, Müllner Haupstr. 48, A-5020 Salzburg, Austria. (Tel +43 662 4482 3601; Fax +43 662 4482 884; e-mail j.beck-mannagetta@salk.at)

BOOK REVIEW

The Oxford Dictionary of Medical Quotations

Reviewed by R M Hamilton

“This is a book of quotations ... can never be complete.” Or can it? The Oxford Dictionary of Medical Quotations is a diverse yet comprehen- sive compilation of over 2500 medically related proverbs and quotations. Whether you are a medical history buff, avid quotation hound, or just trying to find that perfect quote to enhance your next presentation, this book is sure to be indispensable. The quotes are listed under both author and keywords to help you find a specific quote or subject with ease. However, if all you seek are a few moments with the profound to comical musings of doctors, poets, or politicians, you will find this book surprisingly difficult to put down.

R M Hamilton

CORRECTION

Adley MA, Assaf HA, Hussein M. Expression of CD1d in human scalp skin and hair follicles: hair cycle related alterations. J Clin Pathol 2005;58:1279–82. The surname of the first author was spelt incorrectly. The correct name is Adly MA.