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Table 1 Characteristics of study subjects

Characteristic	Control (n = 67)	Early ARM (n = 75)	Late ARM (n = 73)
Age (years)			
<60	25 (37.3)	7 (9.3)	5 (6.8)
60–64	11 (16.4)	10 (13.3)	5 (6.8)
65–69	12 (17.9)	18 (24.0)	14 (19.2)
70–74	17 (25.3)	26 (34.7)	14 (19.2)
≥75	2 (3.0)	14 (18.7)	35 (47.9)
Smoking (pack-years)			
0	32 (47.8)	37 (49.3)	11 (15.1)
1–24	16 (23.9)	14 (18.7)	25 (34.2)
≥25	19 (28.4)	24 (32.0)	37 (50.7)
Hypertension			
Absent	35 (52.2)	34 (45.3)	25 (34.2)
Present	32 (47.8)	41 (54.7)	48 (65.8)
Facial wrinkling			
<0.104	32 (47.8)	18 (24.0)	20 (27.4)
0.104–0.1314	20 (29.9)	29 (38.7)	22 (30.1)
≥0.1314	15 (22.4)	28 (37.3)	31 (42.5)
Facial hyperpigmentation			
<0.0264	19 (28.4)	20 (26.6)	31 (42.5)
0.0264–0.0342	24 (35.8)	27 (36.0)	20 (27.4)
≥0.0342	24 (35.8)	28 (37.3)	22 (30.1)
Upper inner arm skin tone L*			
<59.7	15 (22.4)	26 (34.7)	28 (38.4)
59.7–62.1	21 (31.3)	30 (40.0)	24 (32.9)
≥62.1	31 (46.3)	19 (25.3)	21 (28.8)
Upper inner arm skin tone a*			
<7.2	33 (49.3)	21 (28.0)	18 (24.7)
7.2–8.5	21 (31.3)	25 (33.3)	25 (34.2)
≥8.5	13 (19.4)	29 (38.7)	30 (41.1)
Upper inner arm skin tone b*			
<14.7	29 (43.3)	18 (24.0)	26 (35.6)?
14.7–16.7	19 (28.4)	24 (32.0)	24 (32.9)
≥16.7	19 (28.4)	33 (44.0)	23 (31.5)

Values are number (%).
ARM, age-related maculopathy.

Sample size

From previous work, the sun sensitivity index odds ratio (OR) for late ARM was 3,¹³ so sample size was determined to detect ORs of 3.0 with 80% statistical power at $p \leq 0.05\%$. The required sample size was 66 in each group.

Statistical analysis

Stata 8.1 (Stata Corp, Lakeway Drive College Station, Texas, USA) was used for the statistical analysis. A multivariate logistic regression analysis obtained the maximum likelihood OR estimates and corresponding 95% CIs using ARM stage as a dependent variable. The possible risk factors, age, smoking and hypertension, and sun-related skin factors, facial wrinkling, facial hyperpigmentation and skin tone L*, a* and b*, were included in the models as covariates. Subjects were separated by age into the following groups: <60, 60–64, 65–69, 70–74 and ≥75. Smoking history was analysed as non-smoking, 0–24 pack-years and 25 pack-years or more. Hypertension was dichotomised into absence and presence. Each variable of the skin examination, wrinkling, hyperpigmentation and skin tone (L*, a* or b*), was divided into upper, middle and lower tertiles referenced in statistical analyses. Trend was analysed by a likelihood ratio test using categorical data as continuous variables. Two-sided $p < 0.05$ was considered to be significant.

Table 2 Age, smoking status and hypertension in subjects with age-related maculopathy (ARM) compared with controls

Risk factor	Early ARM vs controls	Late ARM vs controls
Age (years)		
<60	1	1
60–64	3.7 (1.00 to 13.51)	2.8 (0.45 to 17.80)
65–69	5.3 (1.44 to 19.33)	9.7 (1.94 to 48.89)
70–74	5.7 (1.68 to 19.19)	7.3 (1.52 to 34.84)
≥75	25.1 (3.70 to 170.49)	114.5 (15.07 to 869.73)
p Value for trend	0.001	<0.001
Smoking (pack-years)		
0	1	1
0–25	1.2 (0.40 to 3.55)	5.2 (1.39 to 19.36)
≥25	0.9 (0.35 to 2.30)	5.4 (1.61 to 17.90)
p Value for trend	0.856	0.007
Hypertension		
Absent	1	1
Present	1.1 (0.51 to 2.48)	1.1 (0.41 to 3.18)
p Value	0.783	0.788

Values are OR (95% CI) adjusted for age, smoking, hypertension, facial wrinkling, facial hyperpigmentation and skin of upper inner arm (L*, a* or b*).

RESULTS**Study group baseline**

Table 1 lists subjects on the basis of age, smoking status, hypertension, facial wrinkling, facial hyperpigmentation and skin tone.

Age

Mean (SD) age was 63.1 (8.1) years for the controls, 68.7 (6.9) years for the early ARM group, and 72.8 (7.9) years for the late ARM group. The early ARM ($p = 0.001$) and late ARM ($p < 0.001$) groups were significantly older than the controls. Age was a significant factor related to both types of ARM (table 2).

Smoking

Smoking data (mean (SD)) were as follows: 16.1 (21.0) pack-years for controls, 17.8 (25.0) pack-years for the early ARM group, and 32.4 (29.0) pack-years for the late ARM group. Logistic regression analysis showed smoking to be significantly related to late ARM (p for trend = 0.007), but not early ARM (table 2).

Hypertension

Hypertension was not a significant risk for ARM groups (table 2).

Wrinkles

WAF increased with age in patients with ARM and controls (fig 2). However, the observed age dependence of WAF was not statistically significant in either patients or controls. Logistic analysis showed that patients with late ARM had larger WAFs on average than controls after adjustment for age, smoking, hypertension, facial hyperpigmentation and skin tone (p for trend = 0.047), but patients with early ARM did not (table 3).

Pigmentation

Facial pigmentation increased with age in patients with ARM and controls (fig 2). Here again the observed age dependence

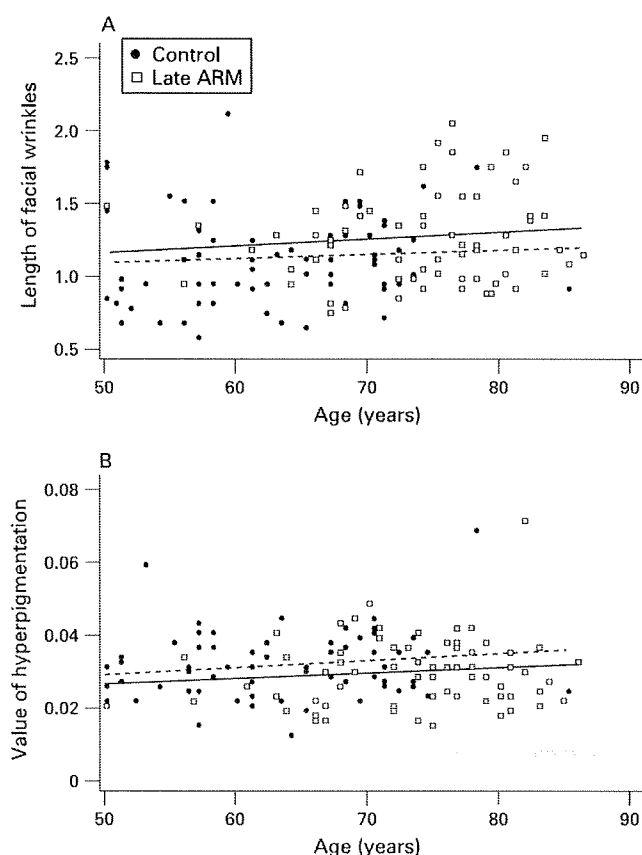


Figure 2 Facial wrinkling (A) and facial pigmentation (B) of patients with late age-related maculopathy (ARM) and controls according to age. (A) Regression lines were drawn separately for patients with late ARM (solid line: $y = 0.09168 + 0.00047x$) and controls (dotted line: $y = 0.08670 + 0.00040x$). (A) Wrinkle area fraction (WAF) increased with age in patients with late ARM and controls. However, the observed age dependence of WAF was not statistically significant in either patients or controls. (B) Regression lines were drawn separately for patients with late ARM (solid line: $y = 0.01898 + 0.00015x$) and controls (dotted line: $y = 0.02152 + 0.00016x$). Facial pigmentation increased with age in patients with late ARM and controls. However, the late ARM group was significantly less pigmented than the control group. Data for the early ARM group were not included to avoid overlapping of points.

was not significant in either patients or controls. Logistic analysis showed that patients with late ARM had smaller areas of pigmentation on average than controls after adjustment for age, smoking, wrinkling and upper inner arm skin (L^* , a^* and b^*). In late ARM cases, a significantly smaller area of hyperpigmentation was found (p for trend = 0.035, table 3). There was no significant difference in area of hyperpigmentation between patients with early ARM and controls.

Skin tone

Mean (SD) indices of skin tone (L^* , a^* and b^*) were: 61.9 (2.9), 7.6 (1.6) and 15.4 (2.6), respectively, for controls; 60.4 (2.3), 8.4 (1.9) and 16.3 (2.2), respectively, for early ARM; 60.4 (3.0), 8.3 (1.8) and 15.4 (2.6), respectively, for late ARM. Patients with ARM had darker, redder and more yellow skin, but no significant difference was seen in skin tone (L^* , a^* and b^*) among the groups (table 3).

Table 3 Wrinkles, pigmentation and skin tone in subjects with age-related maculopathy (ARM) compared with controls

Risk factor	Early ARM vs controls	Late ARM vs controls
Facial wrinkling		
<0.104	1	1
0.104–0.1314	1.4 (0.53 to 3.49)	1.9 (0.54 to 6.56)
≥ 0.1314	2.5 (0.89 to 7.08)	3.8 (1.01 to 13.97)
<i>p</i> Value for trend	0.086	0.047
Facial hyperpigmentation		
<0.0264	1	1
0.0264–0.0342	0.6 (0.24 to 1.69)	0.3 (0.08 to 0.92)
≥ 0.0342	0.6 (0.21 to 1.56)	0.3 (0.08 to 0.92)
<i>p</i> Value for trend	0.332	0.035
Upper inner arm skin tone L^*		
<59.7	1	1
59.7–62.1	0.9 (0.30 to 2.57)	0.5 (0.13 to 2.14)
≥ 62.1	0.9 (0.23 to 3.35)	0.6 (0.10 to 2.94)
<i>p</i> Value for trend	0.848	0.492
Upper inner arm skin tone a^*		
<7.2	1	1
7.2–8.5	1.5 (0.51 to 4.37)	1.5 (0.38 to 5.64)
≥ 8.5	2.1 (0.58 to 7.69)	1.8 (0.37 to 9.17)
<i>p</i> Value for trend	0.257	0.120
Upper inner arm skin tone b^*		
<14.7	1	1
14.7–16.7	1.1 (0.38 to 2.97)	0.7 (0.18 to 2.50)
≥ 16.7	1.2 (0.43 to 3.56)	0.3 (0.08 to 1.34)
<i>p</i> Value for trend	0.697	0.120

Values are OR (95% CI) obtained from the logistic model incorporating age, smoking, hypertension, facial wrinkling, facial hyperpigmentation and upper inner arm skin tone (L^* , a^* and b^*).

DISCUSSION

This paper is, to our knowledge, the first to objectively quantify lifetime exposure to sun and to evaluate the relationship between this and ARM.

Our study shows that facial wrinkle length is positively related to late ARM prevalence, so lifetime exposure to sunlight and late ARM are considered to be positively related. Although it is conventionally held that hyperpigmentation and late ARM are related to lifetime exposure to sunlight, our results, in fact, show the opposite—that is, people with late ARM have fewer facial hyperpigmentation spots. This is difficult to explain; however, a relationship may exist between individual characteristics—that is, a skin that is strongly resistant to tanning and ARM.

Skin wrinkling has been suspected to be strongly associated with lifetime exposure to sunlight.^{22–24} Skin wrinkling is related to an increase in collagen degradation in the extracellular matrix and to a decrease in its synthesis.²⁵ UV irradiation affects wrinkle formation through a cumulative process, so it is logical that facial wrinkling may be an indicator of lifetime exposure to sunlight.^{18 19 22}

A significantly smaller area of hyperpigmented spots was, however, found in late ARM, despite the fact that our previous report concluded that hyperpigmentation was also increased by lifetime exposure to sun.¹⁸ It may be that sunlight/UV irradiation induces changes in skin pigmentation, but the biological pathway differs from that of wrinkle formation. Skin darkening in response to UV irradiation occurs via two distinct pathways: immediate

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pigment darkening and delayed tanning. Delayed tanning involves melanogenesis and is stimulated by DNA photodamage or its repair.²⁶ Melanin synthesis is therefore thought to be a direct response to DNA damage, and melanogenesis is viewed as a biomarker of DNA repair capacity. People with less pigmentation may be more vulnerable to DNA damage caused by exposure to sunlight. Type 1 Fitzpatrick skin types, those with fair-coloured skin and poor tanning ability, are known to be highly susceptible to skin cancer.^{27, 28} We hypothesise that genetic factors related to skin pigmentation are also related to ARM progression in Japanese men in Kagoshima.

With regard to the retina, melanin can act biochemically as an antioxidant in retinal pigment epithelial cells, lessening the harmful effects of UV-induced oxygen free radicals.²⁵ Ocular melanin is thought to be able to physically protect the retina and choroid of pigmented eyes against light-induced cell toxicity through UV absorption. The protection against UV damage afforded by melanin, presumably through a biochemical mechanism, may explain why ARM is more common in lighter-skinned populations.²⁹

This study has certain limitations. There may be concern that exposure of facial skin to sunlight does not exactly reflect exposure of the ocular fundus to sunlight. All participants were male farmers with similar lifestyles in this rural area—for example, sunglasses are rarely used, diets are similar and individual differences would not be large. Although the sample was not large, two well-known risk factors for ARM, aging and smoking, were found to be significant for ARM. Because greater facial wrinkling is also a significant risk factor for late ARM, the sample size was sufficient for a preliminary identification of an additional risk factor for this condition. A potential subject selection bias exists in the study. Subjects with greater exposure to sunlight tend to have severe cataracts and may have been excluded because fundus photographs could not be taken. Of particular note is that age was not matched equally in the ARM groups compared with controls. Although age was applied as a covariant and the multiple variant analysis was performed in an age-adjusted way, the present results should be interpreted with care. It is not possible to say that the present method is perfectly objective. In fact, the definition of wrinkle that we used is subject to interpretation. Although the algorithm thresholds for wrinkle detection are subject to interpretation, the use of computer image analysis to objectively quantify wrinkle length and areas of hyperpigmentation eliminates the potential for bias and error associated with standard visual grading.

There are various other factors that can affect skin condition. Wrinkle length and/or skin pigmentation does not indicate the risk of ARM in every individual clinically. The value of the present method lies rather in its usefulness to study the pathogenesis of ARM.

In conclusion, this study suggests that lifetime exposure to sunlight is associated with ARM in Japanese men living in Kagoshima, Japan. Individual response to acute/chronic exposure to sun may be important in the progression of ARM. Because the objective methods used to measure skin wrinkling and hyperpigmentation such as markers of lifetime exposure to sunlight are standardised across all subjects in the study, and are cost-effective, reproducible and non-invasive, a large-scale follow-up study on different populations would be warranted to better elucidate the role of sun exposure in the progression of ARM and would be useful in the design and development of effective prophylactic treatments.

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REFERENCES

1. **Meyers SM.** A twin study on age-related macular degeneration. *Trans Am Ophthalmol Soc* 1994;**92**:775–843.
2. **Heiba IM, Elston RC, Klein BE, et al.** Sibling correlations and segregation analysis of age-related maculopathy: the Beaver Dam Eye Study. *Genet Epidemiol* 1994;**11**:51–67.
3. **Despriet DD, Klaver CC, Wittteman JC, et al.** Complement factor H polymorphism, complement activators, and risk of age-related macular degeneration. *JAMA* 2006 **19**:296:301–9.
4. **Eye Disease Case-Control Study Group.** Risk factors for neovascular age-related macular degeneration. *Arch Ophthalmol* 1992;**110**:1701–8.
5. **Klein R, Klein BE, Tomany SC, et al.** Ten-year incidence of age-related maculopathy and smoking and drinking: the Beaver Dam Eye Study. *Am J Epidemiol* 2002;**156**:589–98.
6. **Seddon JM, Cote J, Davis N, et al.** Progression of age-related macular degeneration: association with body mass index, waist circumference, and waist-hip ratio. *Arch Ophthalmol* 2003;**121**:785–92.
7. **Khan JC, Thurlby DA, Shahid H, et al.** Genetic Factors in AMD Study. Smoking and age related macular degeneration: the number of pack years of cigarette smoking is a major determinant of risk for both geographic atrophy and choroidal neovascularisation. *Br J Ophthalmol* 2006;**90**:75–80.
8. **Taylor HR, Munoz B, West S, et al.** Visible light and risk of age-related macular degeneration. *Trans Am Ophthalmol Soc* 1990;**88**:163–73.
9. **Taylor HR, West S, Munoz B, et al.** The long-term effects of visible light on the eye. *Arch Ophthalmol* 1992;**110**:99–104.
10. **Cruickshanks KJ, Klein R, Klein BE.** Sunlight and age-related macular degeneration. The Beaver Dam Eye Study. *Arch Ophthalmol* 1993;**111**:514–18.
11. **Tomany SC, Klein R, Klein BE.** The relationship between iris color, hair color, and skin sun sensitivity and the 10-year incidence of age-related maculopathy: the Beaver Dam Eye Study. *Ophthalmology* 2003;**110**:1526–33.
12. **Darzi P, Mitchell P, Heller RF.** Sun exposure and age-related macular degeneration. An Australian case-control study. *Ophthalmology* 1997;**104**:770–6.
13. **Mitchell P, Smith W, Wang JJ.** Iris color, skin sun sensitivity, and age-related maculopathy. The Blue Mountains Eye Study. *Ophthalmology* 1998;**105**:1359–63.
14. **West SK, Rosenthal FS, Bressler NM, et al.** Exposure to sunlight and other risk factors for age-related macular degeneration. *Arch Ophthalmol* 1989;**107**:875–9.
15. **Hirvela H, Luukinen H, Laara E, et al.** Risk factors of age-related maculopathy in a population 70 years of age or older. *Ophthalmology* 1996;**103**:871–7.
16. **Dalcourt C, Carrière I, Ponton-Sanchez A, et al.** Light exposure and the risk of age-related macular degeneration: the Pathologies Oculaires Liees à l'Age (POLA) study. *Arch Ophthalmol* 2001;**119**:1463–8.
17. **Khan JC, Shahid H, Thurlby DA, et al.** Genetic Factors in AMD Study. Age related macular degeneration and sun exposure, iris colour, and skin sensitivity to sunlight. *Br J Ophthalmol* 2006;**90**:29–32.
18. **Hillebrand GG, Miyamoto K, Schnell B, et al.** Quantitative evaluation of skin condition in an epidemiological survey of females living in northern versus southern Japan. *J Dermatol Sci* 2001;**27**(Suppl 1):S42–52.
19. **Akiba S, Shinkura R, Miyamoto K, et al.** Influence of chronic UV exposure and lifestyle on facial skin photo-aging: results from a pilot study. *J Epidemiol* 1999;**9**:S136–42.
20. **Bird AC, Bressler NM, Bressler SB, et al.** An international classification and grading system for age-related maculopathy and age-related macular degeneration. International ARM Epidemiological Study Group. *Surv Ophthalmol* 1995;**39**:367–74.
21. **Prignot J.** Quantification and chemical markers of tobacco-exposure. *Eur J Respir Dis* 1987;**70**:1–7.
22. **Hillebrand GG, Levine MJ, Miyamoto K.** The age-dependent changes in skin condition in ethnic populations from around the world. In: Berardesca E, Leveque J-L, Maibach H (eds). *Ethnic skin and hair*. New York: Informa Healthcare USA, 2006:105.
23. **Miyamoto K, Hillebrand GG.** The Beauty Imaging System: for the objective evaluation of skin condition. *J Cosmetic Sci* 2002;**53**:62–5.
24. **Warren R, Gartstein V, Kligman AM, et al.** Age, sunlight, and facial skin: a histologic and quantitative study. *J Am Acad Dermatol* 1991;**25**:751–60.
25. **Fisher GJ, Wang ZQ, Datta SC, et al.** Pathophysiology of premature skin aging induced by ultraviolet light. *N Engl J Med* 1997;**337**:1419–28.
26. **Agar N, Young AR.** Melanogenesis: a photoprotective response to DNA damage? *Mutat Res* 2005;**571**:121–32.
27. **Fitzpatrick TB.** The validity and practicality of sun-reactive skin types I through VI. *Arch Dermatol* 1988;**124**:869–71.
28. **Nilsson SE, Sundelin SP, Wihlmark U, et al.** Aging of cultured retinal pigment epithelial cells: oxidative reactions, lipofuscin formation and blue light damage. *Doc Ophthalmol* 2003;**106**:13–16.
29. **Kokkinou D, Kasper HU, Schwarz T, et al.** Zinc uptake and storage: the role of fundus pigmentation. *Graefes Arch Clin Exp Ophthalmol* 2005;**243**:1050–5.

Intraocular expression and release of high-mobility group box 1 protein in retinal detachment

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High-mobility group box 1 (HMGB1) protein is a multifunctional protein, which is mainly present in the nucleus and is released extracellularly by dying cells and/or activated immune cells. Although extracellular HMGB1 is thought to be a typical danger signal of tissue damage and is implicated in diverse diseases, its relevance to ocular diseases is mostly unknown. To determine whether HMGB1 contributes to the pathogenesis of retinal detachment (RD), which involves photoreceptor degeneration, we investigated the expression and release of HMGB1 both in a retinal cell death induced by excessive oxidative stress *in vitro* and in a rat model of RD-induced photoreceptor degeneration *in vivo*. In addition, we assessed the vitreous concentrations of HMGB1 and monocyte chemoattractant protein 1 (MCP-1) in human eyes with RD. We also explored the chemotactic activity of recombinant HMGB1 in a human retinal pigment epithelial (RPE) cell line. The results show that the nuclear HMGB1 in the retinal cell is augmented by death stress and upregulation appears to be required for cell survival, whereas extracellular release of HMGB1 is evident not only in retinal cell death *in vitro* but also in the rat model of RD *in vivo*. Furthermore, the vitreous level of HMGB1 is significantly increased and is correlated with that of MCP-1 in human eyes with RD. Recombinant HMGB1 induced RPE cell migration through an extracellular signal-regulated kinase-dependent mechanism *in vitro*. Our findings suggest that HMGB1 is a crucial nuclear protein and is released as a danger signal of retinal tissue damage. Extracellular HMGB1 might be an important mediator in RD, potentially acting as a chemotactic factor for RPE cell migration that would lead to an ocular pathological wound-healing response.

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KEYWORDS: danger signal; high-mobility group box 1 protein; photoreceptor degeneration; retinal detachment; tissue damage; wound healing

Cell death is the predominant event of degenerative tissue damage and can be a trigger that activates the immune system and repair program. Recently, there has been much interest in the pivotal role of endogenous danger signals released during cell death.¹ High-mobility group box 1 (HMGB1) protein is a prototypic innate danger signal, and appears to be crucial in this context because extracellular HMGB1² can modulate inflammation, proliferation, and remodeling, which are involved in the wound-healing process.³

HMGB1 was originally described as an abundant and ubiquitous nuclear DNA-binding protein that had multiple functions dependent on its cellular location.^{2,4} In the nucleus, HMGB1 binds to DNA and is critical for proper transcrip-

tional regulation. It is also called amphoterin and accelerates cellular motility on the cell surface.⁵ HMGB1 is reported to be passively released into the extracellular milieu by necrotic cells, but not by apoptotic cells,⁶ or is exported actively by monocytes/macrophages⁷ and neural cells⁸ upon receiving appropriate stimuli. In damaged tissue, extracellular HMGB1 acts as a necrotic signal, which alerts the surrounding cells and the immune system.² Although extracellular HMGB1 can contribute to normal tissue development and repair, it is also implicated in the pathogenesis of several diseases (including lethal endotoxemia,⁷ disseminated intravascular coagulation,⁹ ischemic brain,¹⁰ tumor,¹¹ atherosclerosis,¹² rheumatoid arthritis,¹³ and periodontitis¹⁴).

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Retinal detachment (RD), the physical separation of photoreceptors from the underlying retinal pigment epithelium (RPE), is one of the main causes of visual loss. Photoreceptor degeneration due to RD is thought to be executed by apoptosis^{15,16} and necrosis,¹⁷ which usually occur after tissue damage. Although retinal cell death and the following reactive responses must occur in almost all forms of retinal disease including RD,¹⁸ data regarding the relationship among cell death, danger, and responses in the eye, have been very limited, especially in terms of danger signals. We previously reported that HMGB1 was significantly elevated in inflamed eyes with endophthalmitis, and suggested a possible link between HMGB1 and ocular inflammatory diseases.¹⁹ On the other hand, considering the properties of HMGB1, we hypothesized that HMGB1 might have some roles in photoreceptor degeneration and subsequent damage-associated reactions in RD.

To investigate whether HMGB1 is involved in the pathogenesis of RD, we first examined the expression and release of HMGB1 both in a retinal cell death *in vitro* and in a rat model of RD-induced photoreceptor degeneration *in vivo*. To focus on human RD, we assessed the intravitreal concentrations of HMGB1 in human eyes affected by RD. Monocyte chemoattractant protein 1 (MCP-1), which was recently documented to be a potential proapoptotic mediator in RD,²⁰ was also measured in the same vitreal samples. We further analyzed the effects of recombinant HMGB1 (rHMGB1) on chemotactic activity in a RPE cell line *in vitro*. Our findings suggest that extracellular HMGB1 is evident in eyes with RD as a danger signal, potentially acting as a chemotactic factor for RPE cell migration that would lead to ocular pathological wound healing.

MATERIALS AND METHODS

Reagents

Full-length, LPS-free rat rHMGB1 protein, which is 99% identical to human HMGB1 and is fully functional on cells of mammalian origin,²¹ was purchased from HMGBiotech (Milan, Italy). Human recombinant MCP-1 (rMCP-1) was purchased from Peprotec (Rocky Hill, NJ). Rabbit polyclonal antibody against HMGB1 was provided by Shino-Test Corporation (Kanagawa, Japan). Antibodies against phospho- and total extracellular signal-regulated kinase (ERK)-1/2 were obtained from Cell Signaling Technology (Beverly, MA). U0126 was obtained from Calbiochem (La Jolla, CA).

Human Vitreal Samples

This study was approved by our institutional ethical committee (Kagoshima University Hospital), and was performed in accordance with the Declaration of Helsinki. All surgeries were performed at Kagoshima University Hospital. All patients gave informed consent before treatment. The clinical histories of all patients were obtained from their medical records. Undiluted vitreal fluid samples (0.5–0.7 ml) were obtained by pars plana vitrectomy. Vitreal humor was

collected in sterile tubes, placed immediately on ice, centrifuged to remove cells and debris, and stored at -80°C until analysis.

Animals

All animal experiments were performed in accordance with the Association for Research in Vision and Ophthalmology Statement for the Use of Animals in Ophthalmic and Visual Research and the approval of our institutional animal care committee (Kagoshima University). Adult male Brown Norway rats (250–300 g; KBT Oriental, Saga, Japan) were housed in covered cages and kept at constant temperature and relative humidity with a regular 12-h light–dark schedule. Food and water were available *ad libitum*.

Surgical Induction of RD

Rat experimental RD was induced as described previously.²² Briefly, the rats were anesthetized with an intramuscular injection of ketamine and xylazine, and their pupils were dilated with topical 1% tropicamide and 2.5% phenylephrine hydrochloride. The retinas were detached using a subretinal injection of 1% sodium hyaluronate (Opegan; Santen, Osaka, Japan) with an anterior chamber puncture to reduce intraocular pressure. Sodium hyaluronate (0.05 ml) was slowly injected through the sclera into the subretinal space to enlarge the RDs. These procedures were performed only in the right eye, with the left eye serving as a control. Eyes with lens injury, vitreal hemorrhage, infection, and spontaneous reattachment were excluded from the following analysis. The rats were killed at 3, 7, and 14 days after treatment, with six animals per each time point.

Cell Culture

The rat immortalized retinal precursor cell line R28, a kind gift from Dr GM Siegel (The State University of New York, Buffalo), was cultured in Dulbecco's modified Eagle's medium (DMEM) high glucose supplemented with 10% fetal bovine serum (FBS), 10 mM non-essential amino acids, and 10 $\mu\text{g}/\text{ml}$ gentamicin as described previously.²³ The human immortalized RPE cell line ARPE-19, obtained from American Type Culture Collection (Manassas, VA), was grown in DMEM/F12 supplemented with 10% FBS, 2% penicillin–streptomycin, and 1% fungizone (all products were obtained from Invitrogen-Gibco, Rockville, MD). Cells were incubated at 37°C in a 5% CO_2 incubator and subcultured with 0.05% trypsin-EDTA. Subconfluent cultures were trypsinized and seeded for the following experiments. ARPE-19 cells were obtained at passage 21 and used at passages 24–30. Increased passage did not alter the following experimental results up to this passage number.

Cell Viability Assay

Cell viability was analyzed by mitochondrial respiratory activity measured using MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenol tetrazolium bromide) assay (Wako Chemicals,

Osaka, Japan), as described previously.²⁴ Briefly, 2×10^5 R28 cells were cultured in 24-well plates (500 μ l medium per well) with or without hydrogen peroxide (1 mM; Merck, Darmstadt, Germany) for 24 h. Then the cells were incubated with MTT (0.5 mg/ml; final concentration) for 3 h. Formazan product was solubilized by the addition of dimethyl sulfoxide for 16 h. Dehydrogenase activity was expressed as absorbance at a test wavelength of 570 nm and at a reference wavelength of 630 nm. Assays were performed in triplicate and repeated three times in independent experiments.

Immunofluorescence for HMGB1 and TUNEL

Indirect immunofluorescence was carried out as described previously,^{19,25} with some modifications. The eyes were harvested and fixed in 4% paraformaldehyde at 4°C overnight. The anterior segment and the lens were removed, and the remaining eye cup was cryoprotected with 10–30% sucrose in phosphate-buffered saline. The eye cups were then frozen in an optimal cutting temperature compound (Sakura Finetech, Tokyo, Japan). Sections were cut at 8 μ m with a cryostat (Leica Microsystems, Wetzlar, Germany). After being incubated with blocking buffer containing 10% goat serum, 1% bovine serum albumin (BSA), and 0.05% Tween-20 for 1 h, the slides were incubated with rabbit polyclonal anti-HMGB1 antibody (1 μ g/ml). After overnight incubation, sections were washed and probed with Alexa-Fluor 594-conjugated goat anti-rabbit IgG F(ab')₂ fragment (Molecular Probes, Carlsbad, CA) for 1 h. In some experiments, TUNEL co-staining was also performed according to the manufacturer's protocol (ApopTag Fluorescein *In situ* Apoptosis Detection kit; Chemicon, Temecula, CA) as previously described.²² Slides were counterstained with DAPI, mounted with Shandon PermaFlour (Thermo Scientific, Waltham, MA), and viewed with a Zeiss fluorescence microscope. Images were captured using the same exposure time for each comparative section. To examine the specificity of immunostaining, the primary antibody was replaced with normal rabbit IgG (1 μ g/ml). Control slides were invariably negative under the same setting (data not shown). For all experiments, at least three sections from each eye were evaluated. To demonstrate the expression patterns of HMGB1 in retinal cells under oxidative stress *in vitro*, R28 cells (2×10^5 cells/500 μ l medium per well) were seeded on four-well glass coverslips and challenged with or without hydrogen peroxide (1 mM) for 1 h. Slides were fixed in 4% paraformaldehyde for 1 h, permeabilized with Triton X-100, and then examined by the same methods as described above.

ELISAs

HMGB1 and MCP-1 were quantified in each human vitreous sample using commercial ELISAs; HMGB1 ELISA kit (Shino-Test Corporation) and Human CCL2/MCP-1 Immunoassay (R&D Systems, Minneapolis, MN), according to the manufacturers' protocols. The detection limits of these kits were 0.2 ng/ml for HMGB1 and 5.0 pg/ml for MCP-1. Con-

centrations below the limits were taken as zero in subsequent analyses. Each sample was run in duplicate and compared with a standard curve. All samples were assessed in a masked manner. The mean concentration was determined per sample. For *in vitro* study, HMGB1 levels in culture supernatants were measured by the same ELISA.

Migration Assay

Cell migration was assayed using a modified Boyden chamber assay as previously described.²⁶ In brief, 5×10^4 ARPE-19 cells resuspended in 200 μ l control medium (1% FBS-DMEM/F12) were seeded onto the upper compartment of the BD Falcon[®] culture inserts (BD Bioscience, San Jose, CA) with an 8- μ m diameter pore size membrane in a 24-well companion plate. The lower chamber was filled with control medium (negative control) and those containing 50, 100, or 200 ng/ml rHMGB1. Because MCP-1 was reported to display a potent chemotactic activity on RPE cells,²⁷ a control medium containing 10 ng/ml rMCP-1 was used as a positive control. After 8-h incubation, cells remaining on the upper surface of the filters were removed mechanically, and those that had migrated to the lower surface were fixed with methanol, stained with Diff-Quick (Dade-Behring, Deerfield, IL), and counted in five randomly selected high-power fields ($\times 100$) per insert. Migration index (% of control) was calculated by dividing the number of migrating cells in the presence of chemoattractants by the cells that migrated in response to the negative control. To inhibit ERK-1/2 activity, the cells were pretreated with 1, 5, or 10 μ M U0126, or vehicle (0.1% dimethyl sulfoxide) for 30 min, prior to the addition of rHMGB1. U0126 is an inhibitor of active and inactive MEK-1/2, the MAPK kinase that activates ERK-1/2. These concentrations of U0126 and dimethyl sulfoxide had no effect on ARPE-19 cell viability determined by MTT assay in our study (data not shown) and in a previous report.²⁸ Assays were performed in triplicate and repeated three times in independent experiments.

Immunoblotting

ARPE-19 cells (5×10^5) were subcultured on 6-cm tissue culture dishes. Then, the cells were serum starved overnight in DMEM/F12 and stimulated with 100 ng/ml rHMGB1 for the indicated times. Activation of ERK-1/2 was analyzed as described previously.²⁴ In brief, after treatment, whole cells were lysed with SDS sample buffer and an equal volume of protein extracts was loaded onto 12% SDS-polyacrylamide gels and then transferred onto a nitrocellulose membrane. The membrane was blocked by incubation with 5% non-fat dry milk plus 1% BSA in TBST (0.02% Tween-20 in Tris-buffered saline, pH 7.4) for 1 h at room temperature. The membrane was then incubated with the antibody against phospho-ERK-1/2 (diluted 1/1000) at 4°C overnight. The blots were subsequently probed with secondary anti-rabbit antibodies conjugated to horseradish peroxidase (diluted 1/3000 in TBST), and images were developed using the en-

hanced chemiluminescence system (GE Healthcare). The membrane was stripped and reprobed with an antibody against total ERK-1/2 (diluted 1/1000).

Statistical Analysis

The vitreous HMGB1 and MCP-1 concentrations in each group were compared using the Mann-Whitney *U*-test. The correlation between HMGB1 and MCP-1 in RD samples was analyzed using a simple linear regression analysis and Spearman's rank correlation coefficient. All *in vitro* data are presented as mean \pm s.d. and the significance of differences between groups was determined by Student's *t*-test. *P*-value less than 0.05 was considered significant.

RESULTS

HMGB1 is Present in Cultured Retinal Cell and Released Extracellularly by Oxidative Stress-Induced Cell Death

We first evaluated the expression patterns and cellular distribution of HMGB1 in an R28 retinal cell line with or without oxidative stress, a known cause of neurodegeneration.²⁹ Excessive reactive oxygen species can lead to the destruction of cellular components and ultimately induce cell death through apoptosis or necrosis. To induce oxidative stress, we used a toxic dose (1 mM) of hydrogen peroxide, which was reported to stimulate monocytes/macrophages to release HMGB1 actively and passively.³⁰ As shown in Figure 1a, HMGB1 immunoreactivity was stably present in the nucleus of unstimulated R28 cells, and relatively weak staining was observed in the cytoplasm. By contrast, 1 h after exposure to 1 mM hydrogen peroxide, some cells seemed to present rather high levels of HMGB1 in their nucleus as well as their cytoplasm compared with those under an unstimulated condition. However, in the other cells, the nuclear HMGB1 was diminished or appeared to be released into the cytoplasm. These results indicate that the nuclear HMGB1 could be varied by death stress and be released into the cytoplasm according to the degree of stress. Hydrogen peroxide (1 mM) treatment for 24 h, in which about 90% of the cells lost their viability (Figure 1b), induced a massive release of HMGB1 from the cells to the cell supernatants (Figure 1c). Taken together, these findings suggested that HMGB1 could relocate from the nucleus to the cytoplasm for eventual release in dying retinal cells, and that the extracellular release of HMGB1 in the eye might be increased dependent on the extent of retinal cell death.

HMGB1 is Abundantly Expressed in Rat Retina and Released after RD

As the above findings indicated that HMGB1 was of relevance to retinal cell death, we investigated whether HMGB1 was maintained in the rat retina and how HMGB1 would vary after RD. As it was reported that HMGB1 in rat photoreceptors had a light-sensitive circadian rhythmic expression,²⁵ we performed all animal studies on a regular time schedule, and all eyes were set to be almost equally exposed to

light. As shown in Figure 2, HMGB1 immunoreactivity was well represented in sections of the normal control rat retina and, as expected, colocalized with DAPI-positive nuclei (Figure 2a, d and g). HMGB1 staining in the normal rat retina was prominent in the nuclei of ganglion cell layer, inner nuclear layer, outer nuclear layer, and RPE, and was also apparent in the photoreceptor inner segments. In particular, HMGB1 was localized in photoreceptor at the nuclear periphery, and HMGB1 levels were higher in the inner nuclear layer than the outer nuclear layer as opposed to DAPI staining, which preferred to bind to heterochromatic DNA. This was consistent with the previous report²⁵ that HMGB1 was preferentially colocalized with euchromatin, which was often under active transcription and was stained less by DAPI. Interestingly, HMGB1 appeared to be robustly upregulated in both the photoreceptors and the other retinal cells at day 3 after RD inductions, and DAPI staining was inversely downregulated at the same time (Figure 2b, e and h). As previous reports demonstrated that dramatic alterations of retinal gene expression occurred after RD,³¹ this high level of HMGB1 expression might be related to the active gene transcription. HMGB1 in the nucleus might be stress responsive and necessary for proper transcription after RD tissue damage. Afterwards, the nuclear HMGB1 expression in the photoreceptors seemed to subside at day 7, while still clearly remained in the inner segments (Figure 2c, f and i), gradually decreasing along with the thinning of the outer nuclear layer due to photoreceptor degeneration by day 14 (data not shown).

Although HMGB1 expression was increased in the photoreceptors of the detached retina at day 3, it was not homogeneous, but was rather heterogeneous. To clarify the relationship between the upregulation of HMGB1 and photoreceptor cell death, especially with DNA damage, the RD retina at day 3 was co-stained with TUNEL, which could detect apoptotic and potentially necrotic cell death by labeling the damaged DNA (Figure 3a-c). Previous studies indicated that HMGB1 could not be released from apoptotic cells⁶ and the apoptotic photoreceptors were prominent in this RD model at day 3 after RD.²² We also confirmed remarkable numbers of apoptotic photoreceptors in the detached retina at day 3 (Figure 3b), and found that the early faint TUNEL-positive nuclei had relatively low levels of HMGB1 and fragmented nuclei, which were brightly stained by TUNEL, had almost no apparent HMGB1 immunoreactivity (Figure 3c), suggesting that apoptotic dying cells might lose the expression of HMGB1 to maintain the proper gene transcription. It might be indispensable for the surviving photoreceptors to maintain and/or boost the nuclear HMGB1 in RD.

In the subretinal space of RD at day 7, HMGB1-positive and TUNEL-negative debris could be observed (Figure 3d, arrows), which might be released by necrotic photoreceptors and/or degraded inner segments, and spread diffusely into the vitreous cavity if a retinal break was present. It was also

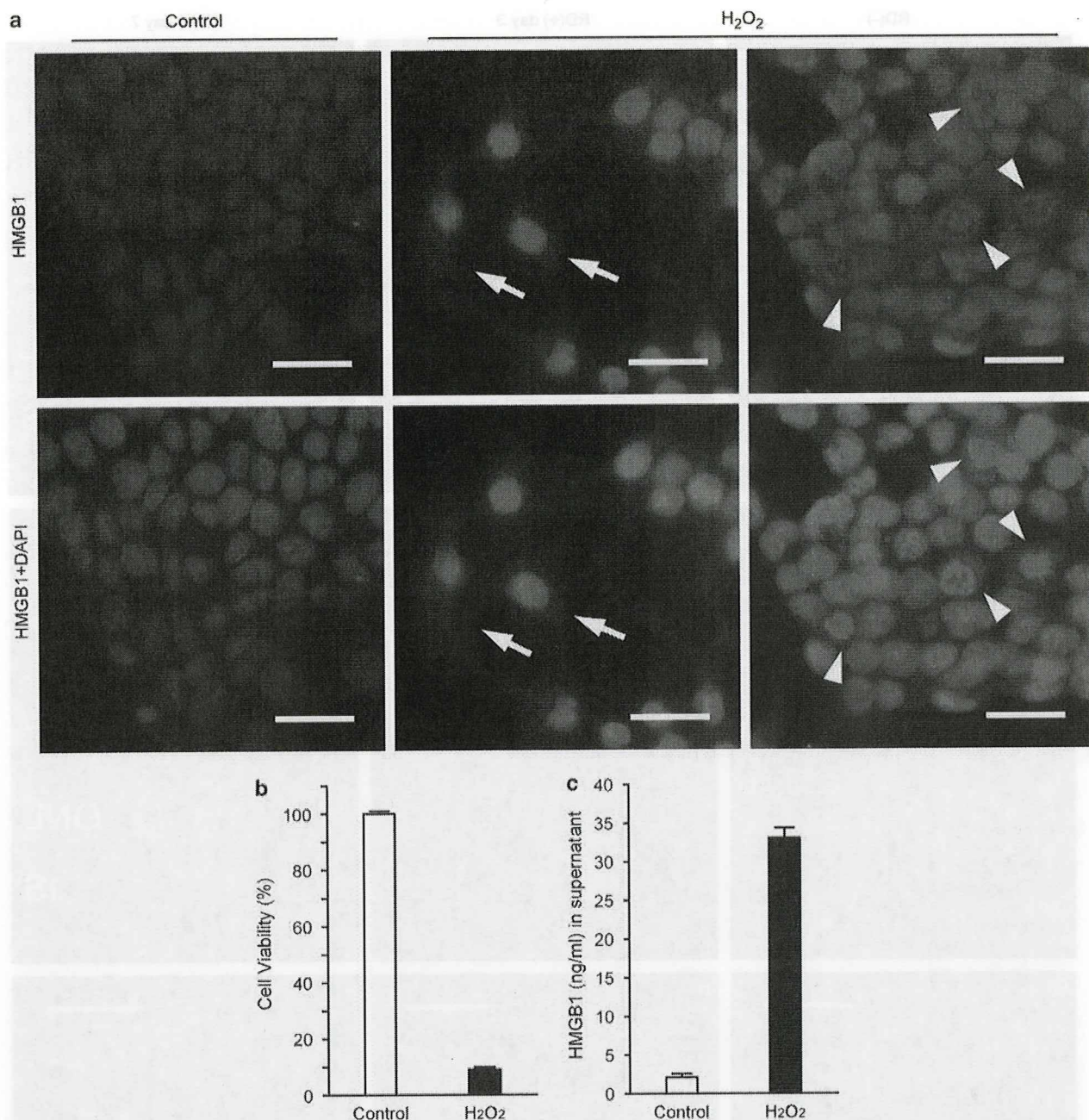
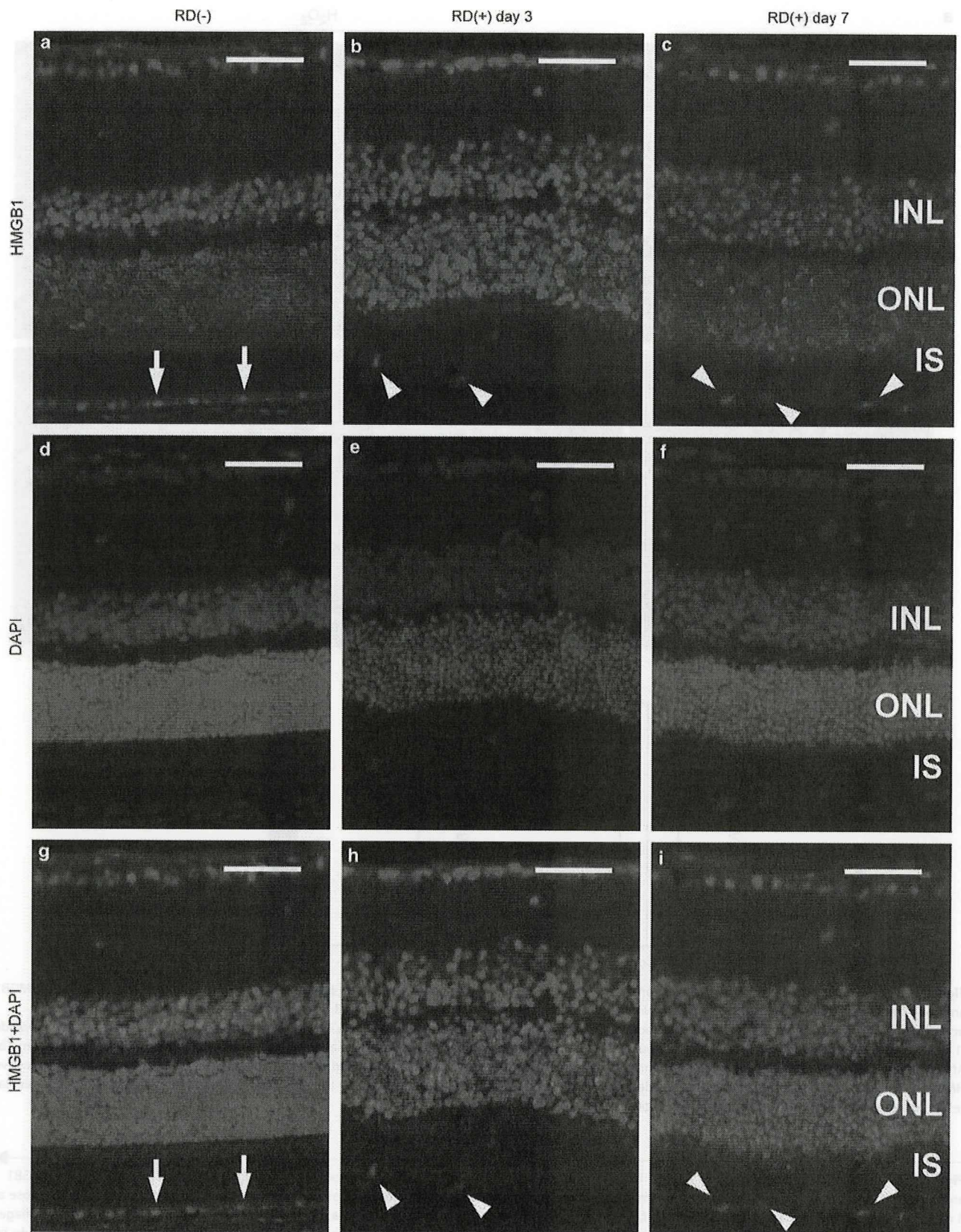


Figure 1 Release of HMGB1 from R28 retinal neuronal cells exposed to excessive oxidative stress. (a) Immunofluorescence was performed with anti-HMGB1 antibody (red) and DAPI (blue). HMGB1 is predominantly present in the nuclei of unstimulated R28 cells (left column). Some cells present robust upregulation of HMGB1 in the nuclei, as well as relocation into the cytoplasm (middle column; arrows) on 1 h exposure to a toxic dose of hydrogen peroxide (1 mM). In the other cells, the nuclear HMGB1 is found to be diminished or released into the cytoplasm (right column; arrowheads). Scale bars: 20 μ m. (b) After 24 h exposure to 1 mM hydrogen peroxide, the cell viability analyzed by MTT assay is decreased to about 10% compared with the control. (c) Massive HMGB1 release into the culture supernatant was determined by ELISA after the same treatment as (b). The data represent the mean \pm s.d. ($n = 3$). Similar results were obtained from three independent experiments.

Figure 2 Immunofluorescence analysis of HMGB1 in a rat model of RD. Representative photomicrographs of retinal sections labeled with anti-HMGB1 antibody (red; a–c) and DAPI (blue; d–f). Merged images (g–i) are also presented. The retinal sections were derived from the control eye (a, d, g), those at 3 days (day 3; b, e, h), or 7 days after RD (day 7; c, f, i). Arrows point to retinal pigment epithelium (a, g), and arrowheads indicate subretinal macrophages (b, c, h, i). Note that expression of HMGB1 is augmented especially in ONL at day 3 after RD, whereas the upregulation in ONL appears to be subsided by day 7 ($n = 6$ for each time point). Scale bars: 50 μ m. INL, inner nuclear layer; IS, inner segment; ONL, outer nuclear layer.



reported that macrophages migrated into the subretinal space of this RD model.³² The migrating macrophages also had abundant HMGB1 expression (Figure 3d, arrowheads), and might have released HMGB1 actively in this space. In line with these data, a large amount of extracellular HMGB1 must be present at least in the subretinal space after RD.

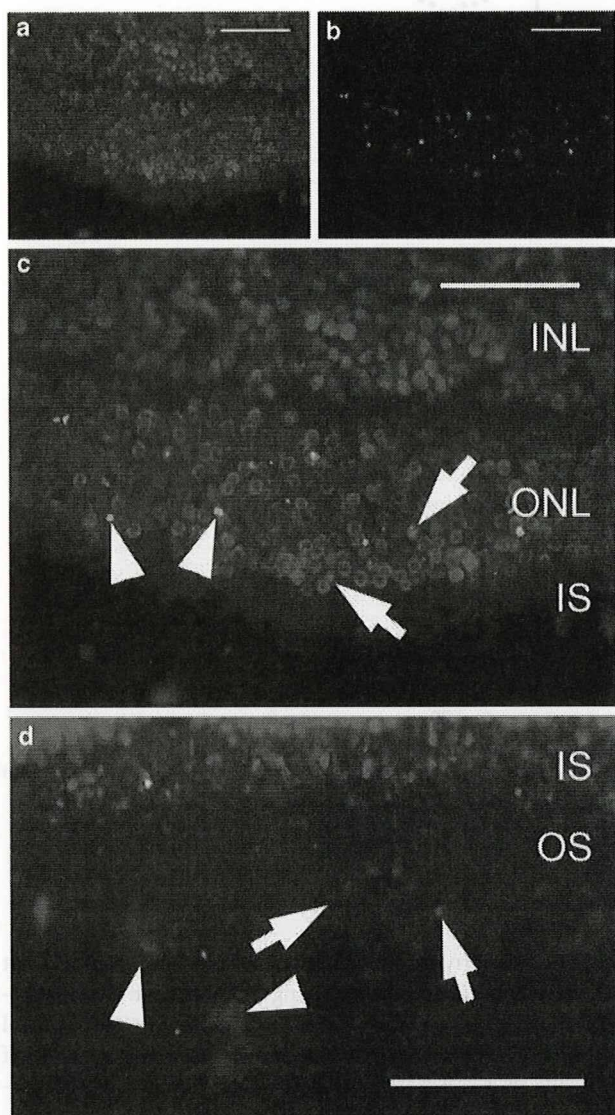


Figure 3 Expression of HMGB1 in DNA-damaged photoreceptors (a–c) and release of HMGB1 in the subretinal space (d). Representative photomicrographs of anti-HMGB1 antibody (red; a), TUNEL (green; b), and merged image (c) from rat retinal sections at 3 days after RD (n = 6). The early faint TUNEL-positive nuclei (c; arrows) have relatively low levels of HMGB1 and the fragmented nuclei (c; arrowheads) have almost no apparent HMGB1 immunoreactivity. (d) Representative photomicrograph of a merged image of anti-HMGB1 (red), DAPI (blue), and TUNEL (green) obtained from rat retinal sections at 7 days after RD (n = 6). HMGB1-positive and TUNEL-negative debris (d; arrows) and migrating macrophages with abundant HMGB1 expression (d; arrowheads) can be observed in the subretinal space. Scale bars: 50 μm. INL, inner nuclear layer; IS, inner segment; ONL, outer nuclear layer; OS, outer segment.

Vitreous HMGB1 and MCP-1 Levels in Patients with RD

The result obtained from the rat model of RD is the first evidence to our knowledge that HMGB1 is involved in RD-induced photoreceptor degeneration. Next, we tested whether extracellular HMGB1 could also be detected in human vitreous samples of RD. Samples were harvested from 35 eyes with RD, including rhegmatogenous RD, RD with macular hole, and atopic RD and 19 eyes with control diseases, including idiopathic epiretinal membrane and idiopathic macular hole (Table 1). The vitreous HMGB1 and MCP-1 levels were significantly higher in the eyes with RD than in those with control diseases (Figure 4). The median HMGB1 level was 1.4 ng/ml (range, 0–28.3) in the eyes with RD and 0.6 ng/ml (range, 0–1.3) in those with control diseases (P < 0.001; Figure 4a). The median MCP-1 level was 1383.2 pg/ml (range, 39.8–5436.1) in the RD eyes and 404.4 pg/ml (range, 17.9–1168.9) in the control eyes (P < 0.0001; Figure 4b). The vitreous concentration of HMGB1 was correlated significantly with that of MCP-1 in the 35 eyes with RD by a simple linear regression (r = 0.593, P < 0.001; Figure 4c) and by Spearman’s rank correlation coefficient (r = 0.613, P < 0.001). On the other hand, there was no significant relationship between the vitreous concentrations of HMGB1 and MCP-1 in the 19 eyes of control patients (data not shown). Although there was no significant difference, the HMGB1 levels in the eyes with proliferative vitreoretinopathy (PVR), a condition of retinal fibrosis that follows severe long-standing RD, tended to be lower than those without PVR (Figure 4d). These findings showed that HMGB1 could be released not only in the subretinal space but also in the vitreous cavity after RD-induced photoreceptor degeneration, and that the HMGB1 release was coincident with vitreous MCP-1 expression.

Table 1 Characteristics of the patients

Characteristics	Retinal detachment (n = 35)	Control diseases (n = 19)
Age (years)	57.3 ± 16.3	68.2 ± 8.7
Female sex, no. (%)	19 (54)	10 (53)
Patients with PVR, no. (%)	6 (17)	—
<i>Subgroups, no. (%)</i>		
Rhegmatogenous retinal detachment	28 (80)	—
Retinal detachment with macular hole	5 (14)	—
Atopic retinal detachment	2 (6)	—
Idiopathic epiretinal membrane	—	7 (37)
Idiopathic macular hole	—	12 (63)

PVR, proliferative vitreoretinopathy.

Values are expressed as mean ± s.d. Dashes denote not applicable.

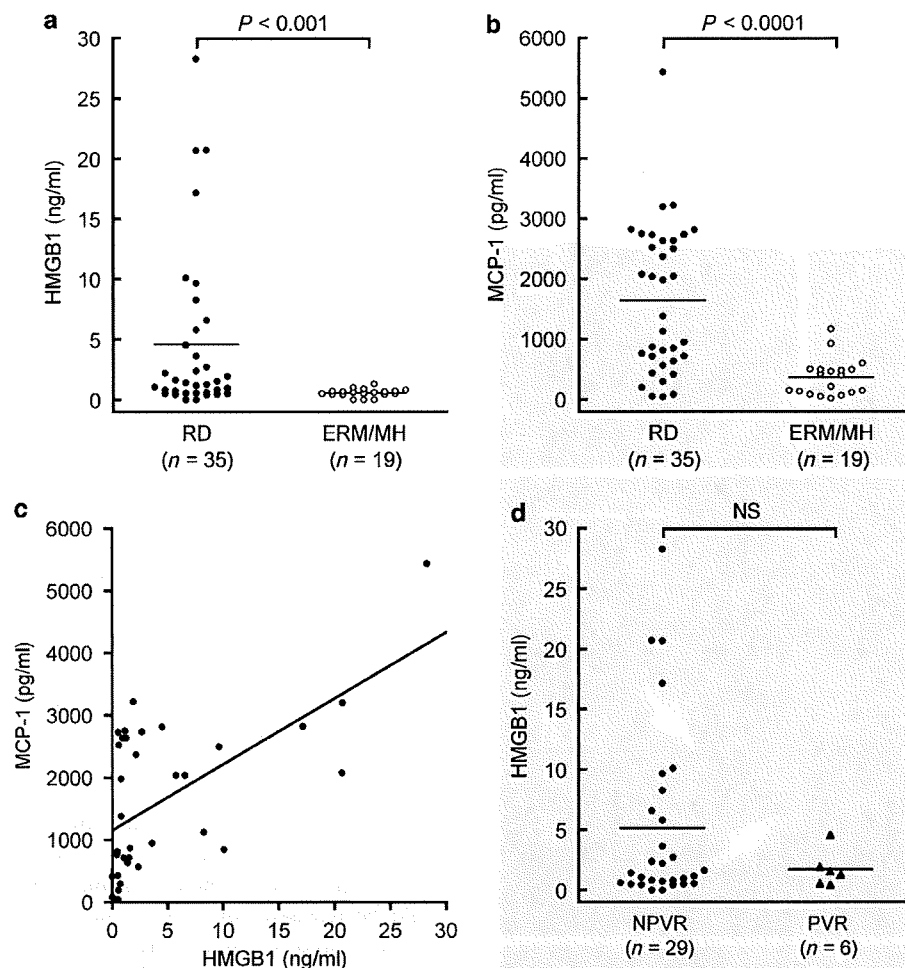


Figure 4 Vitreous levels of HMGB1 and MCP-1. The vitreous HMGB1 (a) and MCP-1 (b) levels are significantly higher in eyes with RD than in those with control diseases (idiopathic epiretinal membrane or idiopathic macular hole). Each bar indicates the average value. (c) Scatter plot for the correlation between vitreous levels of HMGB1 and MCP-1 in eyes with RD (simple linear regression, $r = 0.593$, $P < 0.001$; Spearman's rank correlation coefficient, $r = 0.613$, $P < 0.001$). (d) The HMGB1 levels in the eyes with PVR tend to be lower than those without PVR. ERM/MH, epiretinal membrane/macular hole; NPVR, no PVR; PVR, proliferative vitreoretinopathy.

RPE Cells Respond Chemotactically to Extracellular HMGB1 through an ERK-Dependent Mechanism

Previous reports have shown that extracellular HMGB1 is a chemoattractant for a variety of cell types.^{21,33,34} We investigated whether HMGB1 is also a chemoattractant for RPE cells. Extracellular HMGB1 has been reported to engage multiple receptors, including the receptor for advanced glycation end products (RAGE) and Toll-like receptors 2 and 4.^{2,4} In particular, RAGE has been thought to be a crucial receptor for HMGB1-induced cell migration through ERK activation.³³ The expression of RAGE at the RNA and protein level was identified in human RPE³⁵ and ARPE-19 cells^{36,37} in previous studies. It was also shown that the expression of RAGE and HMGB1 was colocalized in the proliferative membrane from an eye with proliferative retinal disease.³⁸ We, therefore, performed a migration assay using modified Boyden chambers with various concentrations of rHMGB1.

The representative photographs in Figure 5 show that rHMGB1 was capable of inducing a significant level of migration (Figure 5b) above that obtained with the control medium (Figure 5a). HMGB1 stimulated the migration of RPE cells in a concentration-dependent manner with a 2.7-fold maximal response at 100 ng/ml (Figure 5c). This maximal response to rHMGB1 was slightly stronger than that induced by rMCP-1 (10 ng/ml). Next, we investigated whether HMGB1 induced phosphorylation of ERK-1/2 in ARPE-19 cells; we stimulated cells with 100 ng/ml rHMGB1 for various time periods and used western blotting with an anti-phospho-ERK-1/2 antibody on whole-cell lysates (Figure 6a). Little phosphorylation of ERK-1/2 could be observed in unstimulated ARPE-19 (at 0 min), but a prominent increase was detected after 5 min of stimulation with rHMGB1. Figure 6a shows that phosphorylation of ERK-1/2 was augmented from 5 to 60 min after rHMGB1 stimulation in comparison

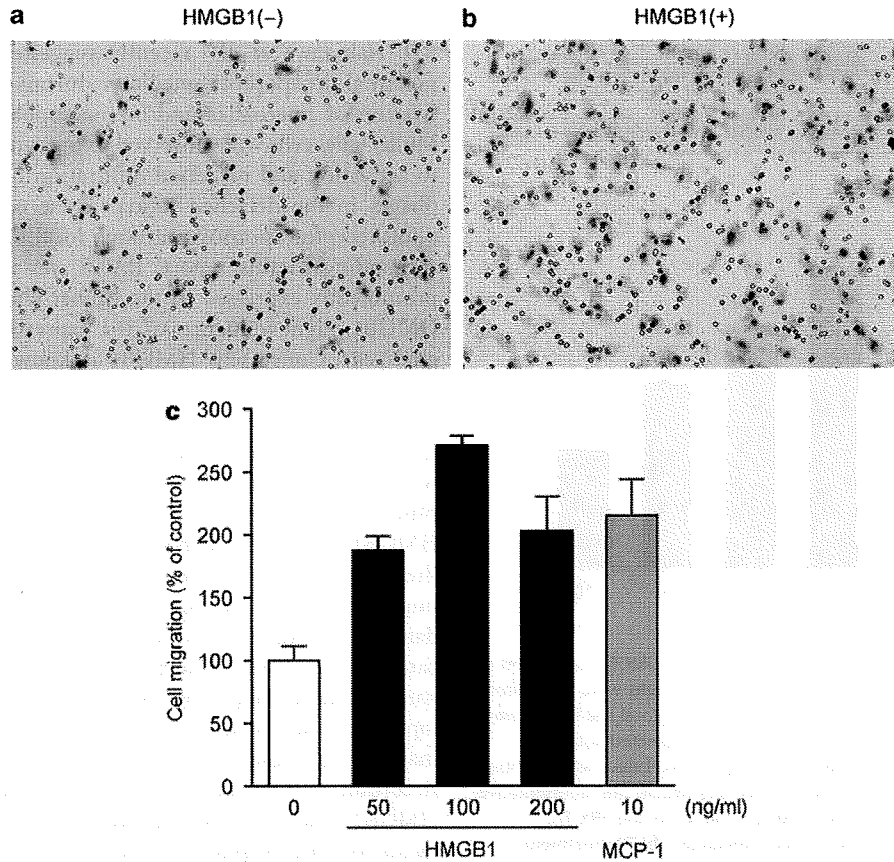


Figure 5 RPE cells migrate in response to HMGB1. Representative photographs of ARPE-19 cells stained with Diff-Quick after migration toward control medium (a) or 100 ng/ml HMGB1 (b). Original magnification: $\times 100$. (c) HMGB1 stimulated ARPE-19 cell migration in a concentration-dependent manner with a 2.7-fold maximal response at 100 ng/ml. The data represent the mean \pm s.d. ($n = 3$). All treatments increase the migratory response relative to the control ($P < 0.01$ in Student's *t*-test). Similar results were obtained from three independent experiments.

with unstimulated ARPE-19 (time 0). To demonstrate that the ERK signaling induced by HMGB1 was in fact linked to the migration of RPE cells, we next inhibited ERK-1/2 and assessed cell migration to HMGB1. Pretreatment of ARPE-19 with U0126 abrogated the migration toward rHMGB1 (Figure 6b). Thus, the ERK pathway appears to play an essential role in HMGB1-induced RPE cell migration.

DISCUSSION

Our findings suggest a possible role of HMGB1 in RD, as an essential nuclear protein and a principal danger signal for photoreceptor degeneration. Using an *in vitro* assay of retinal cell death induced by excessive oxidative stress, we found that HMGB1 was augmented in the nucleus by the stress and released into the extracellular space during cell death. On the basis of immunohistochemical analyses of a rat model of RD-induced photoreceptor degeneration, augmentation of HMGB1 in the nucleus is also observed *in vivo* and appears to be crucial for the proper transcription of photoreceptors after RD. Moreover, double labeling with TUNEL reveals defects of upregulation of the nuclear HMGB1 in the DNA-

damaged photoreceptors, which are presumably programmed dying photoreceptors. Therefore, we propose that the nuclear HMGB1 in the retinal cells might be critical for retinal cell survival under death stresses both in the *in vivo* RD and *in vitro* retinal cell death. These results for ocular HMGB1 are compatible with previous reports that HMGB1 is a vital nuclear protein and has a protective role in the nucleus.^{2,4}

In a previous animal study, Erickson *et al*¹⁷ reported that a loss of photoreceptors in a cat model of RD occurred due to necrosis. During studies on RD, photoreceptor degeneration after RD had been thought to be mainly caused by apoptosis.^{15,16} Hisatomi *et al*³² demonstrated the presence of apoptotic debris in the subretinal space of rat RD. In the present study, considering our immunohistochemistry results from the same rat model of RD, so-called necrotic debris, which is HMGB1 positive and TUNEL negative, was found to be present. On the basis of the previous finding of the preferential release of HMGB1 from necrotic cells,⁶ this suggests that necrosis might still be a fundamental type of photoreceptor cell death after RD.

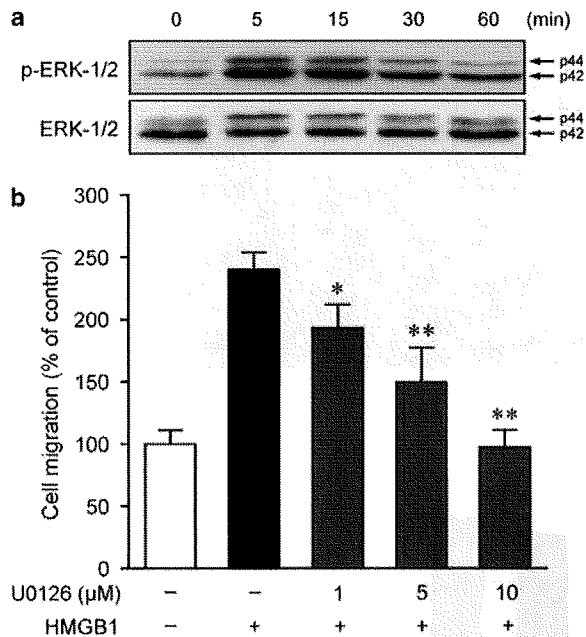


Figure 6 The phosphorylation of ERK is induced by HMGB1 and linked to HMGB1-induced migration of RPE cells. (a) ARPE-19 cells were stimulated with HMGB1 (100 ng/ml) for 5, 15, 30, or 60 min, and total cell lysates were analyzed by western blot. ERK-1/2 activation was detected with anti-phospho-ERK-1/2 antibody (p-ERK-1/2). Stripped membrane was re probed with the antibody against total ERK-1/2 (ERK-1/2). Results are representative of three independent experiments. HMGB1 augments the ERK-1/2 phosphorylation from 5 to 60 min after stimulation. (b) Pretreatment of ARPE-19 with U0126 inhibits the cell migration toward HMGB1 (100 ng/ml) in a dose-dependent manner. The data represent the mean \pm s.d. ($n = 3$). Similar results were obtained from three independent experiments. * $P < 0.05$, ** $P < 0.01$, compared with vehicle-treated control.

Furthermore, exploring human vitreous samples by ELISA, we found that both HMGB1 and MCP-1 are increased significantly in eyes with RD. Although MCP-1 is a well-known mediator for RD,³⁹ to our knowledge, this is the first report indicating that extracellular HMGB1 might also be of relevance to human RD. HMGB1 concentration tended to be high in the eye without PVR, but not so with PVR. One possible explanation for this tendency is that HMGB1 might be sequestered and/or masked in PVR, the advanced stage of RD. HMGB1 binds tightly to heparin and proteoglycans with heparan sulfate,⁵ and it is also reported that such proteoglycans are abundantly present as the ocular extracellular matrix, even in RD.⁴⁰ Hence, these molecules might affect the HMGB1 concentration in the vitreous humor. Nevertheless, this possibility does not negate the presence of HMGB1. Considering the results obtained with the rat RD model, extracellular HMGB1 could be present at much higher levels, at least in the subretinal fluid of RD, and it might serve as a persistent signal adhering to the local damaged retina and/or surrounding matrix as previously described.⁵

It is also of importance that HMGB1 is significantly correlated with MCP-1 in RD vitreous. The secretion of MCP-1

might parallel the extent of photoreceptor degeneration of RD. Nakazawa *et al*²⁰ recently suggested that MCP-1 is a potential proapoptotic mediator during RD through the activation of microglia and/or macrophages. In their study, Müller-glial cells were observed to upregulate MCP-1, leading to activation and increased infiltration of microglia/macrophages in the detached retina. These cells induced further photoreceptor apoptosis through local oxidative stress. Corresponding to this report, RAGE was also reported to be prominently expressed in the Müller-glial cells.⁴¹ Therefore, HMGB1 might influence MCP-1 expression through Müller-glial cells. Conversely, HMGB1 is known to be released by activated monocytes/macrophages.⁷ MCP-1 is a potent stimulator and chemoattractant for monocytes/macrophages,⁴² and these cells were observed in the subretinal space of RD with abundant HMGB1 expression. This would also be another possible explanation for the parallel increases of HMGB1 and MCP-1. Nevertheless, the positive correlation of these molecules indicates that cell death-related mediators might be highly orchestrated in ocular degenerative tissue damage. Several studies suggest that extracellular HMGB1 can aggravate tissue damage in neuronal tissues.^{10,43} In these studies, extracellular HMGB1 plays a key role in the development of neuronal injury through the induction of inflammation, microglial activation, and neuronal excitotoxicity. According to these recent reports, the presence of extracellular HMGB1 concomitantly with MCP-1 is a possible deteriorating factor for RD, in spite of its essential role in the nucleus.

PVR is one of the most threatening complications of RD. It is thought to be a reactive process to retinal injury, in other words, it is one of the wound-healing responses in the eye. RPE cells are known to be detectable in the fibrotic proliferative membranes of PVR, and play an important role in the pathogenesis of PVR.⁴⁴ Thus, the effects of a molecule on PVR formation could be traced to RPE migration, at least in part. Here, we demonstrate that extracellular HMGB1 promotes RPE cell migration by chemotaxis *in vitro*. This result is consistent with previous reports of HMGB1-induced cell migration in various cell types, such as smooth muscle cells,^{21,33} fibroblasts,⁴⁵ and chondrocytes.³⁴ We also found that HMGB1 activated phosphorylation of ERK-1/2 in RPE cells and the migration induced by HMGB1 was dependent on ERK phosphorylation. The phosphorylation of ERK is associated with cell proliferation and cell migration through effects on cell-matrix contacts.⁴⁶ It was also reported to be found in Müller-glial cells after RD.⁴⁷ Taken together, our results suggest that extracellular HMGB1 from dying ocular cells might affect retinal cells through ERK phosphorylation and potentially serve to promote the formation of PVR, which is wound healing, but has a pathological meaning in the eye. Several new strategies for prevention of ocular fibrosis, especially targeting specific signaling pathways, have been proven to be beneficial in animal models.⁴⁸⁻⁵⁰ We propose that the identification and further characterization of danger signals, including HMGB1, would provide a novel

perspective for better understanding the molecular pathogenesis of PVR before applying these promising therapeutic manipulations to human subjects.

It has been suggested that post-transcriptional modifications of HMGB1, such as acetylation, methylation, and phosphorylation, might influence its activity.⁵¹ Some recent reports also demonstrate that the proinflammatory activity of HMGB1 is due to combined action with other molecules.⁵² The present data are mostly limited to the presence of HMGB1 rather than its biological activity, and we do not address what modifications or molecules are involved in intraocular HMGB1. However, we identify for the first time that HMGB1 is evident in a typical retinal injury of human RD, in which nuclear HMGB1 is a crucial nuclear protein and extracellular HMGB1 is a danger signal that might be required for the ocular wound-healing response. Our findings might have relevance for the underlying mechanisms of degenerative neuronal diseases. Further detailed studies will be needed to obtain more accurate knowledge and therapeutic value of HMGB1 in human diseases.

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- Bianchi ME. DAMPs, PAMPs and alarmins: all we need to know about danger. *J Leukoc Biol* 2007;81:1–5.
- Ulloa L, Messmer D. High-mobility group box 1 (HMGB1) protein: friend and foe. *Cytokine Growth Factor Rev* 2006;17:189–201.
- Martin P. Wound healing—aiming for perfect skin regeneration. *Science* 1997;276:75–81.
- Lotze MT, Tracey KJ. High-mobility group box 1 protein (HMGB1): nuclear weapon in the immune arsenal. *Nat Rev Immunol* 2005;5:331–342.
- Huttunen HJ, Rauvala H. Amphotericin as an extracellular regulator of cell motility: from discovery to disease. *J Intern Med* 2004;255:351–366.
- Scaffidi P, Misteli T, Bianchi ME. Release of chromatin protein HMGB1 by necrotic cells triggers inflammation. *Nature* 2002;418:191–195.
- Wang H, Bloom O, Zhang M, *et al*. HMGB-1 as a late mediator of endotoxin lethality in mice. *Science* 1999;285:248–251.
- Passalacqua M, Patrone M, Picotti GB, *et al*. Stimulated astrocytes release high-mobility group 1 protein, an inducer of LAN-5 neuroblastoma cell differentiation. *Neuroscience* 1998;82:1021–1028.
- Ito T, Kawahara K, Nakamura T, *et al*. High-mobility group box 1 protein promotes development of microvascular thrombosis in rats. *J Thromb Haemost* 2007;5:109–116.
- Kim JB, Sig Choi J, Yu YM, *et al*. HMGB1, a novel cytokine-like mediator linking acute neuronal death and delayed neuroinflammation in the postischemic brain. *J Neurosci* 2006;26:6413–6421.
- Campana L, Bosurgi L, Rovere-Querini P. HMGB1: a two-headed signal regulating tumor progression and immunity. *Curr Opin Immunol* 2008;20:518–523.
- Inoue K, Kawahara K, Biswas KK, *et al*. HMGB1 expression by activated vascular smooth muscle cells in advanced human atherosclerosis plaques. *Cardiovasc Pathol* 2007;16:136–143.
- Taniguchi N, Kawahara K, Yone K, *et al*. High mobility group box chromosomal protein 1 plays a role in the pathogenesis of rheumatoid arthritis as a novel cytokine. *Arthritis Rheum* 2003;48:971–981.
- Morimoto Y, Kawahara KI, Tancharoen S, *et al*. Tumor necrosis factor- α stimulates gingival epithelial cells to release high mobility-group box 1. *J Periodontol Res* 2008;43:76–83.
- Cook B, Lewis GP, Fisher SK, *et al*. Apoptotic photoreceptor degeneration in experimental retinal detachment. *Invest Ophthalmol Vis Sci* 1995;36:990–996.
- Arroyo JG, Yang L, Bula D, *et al*. Photoreceptor apoptosis in human retinal detachment. *Am J Ophthalmol* 2005;139:605–610.
- Erickson PA, Fisher SK, Anderson DH, *et al*. Retinal detachment in the cat: the outer nuclear and outer plexiform layers. *Invest Ophthalmol Vis Sci* 1983;24:927–942.
- Vazquez-Chona F, Song BK, Geisert Jr EE. Temporal changes in gene expression after injury in the rat retina. *Invest Ophthalmol Vis Sci* 2004;45:2737–2746.
- Arimura N, Ki IY, Hashiguchi T, *et al*. High-mobility group box 1 protein in endophthalmitis. *Graefes Arch Clin Exp Ophthalmol* 2008;246:1053–1058.
- Nakazawa T, Hisatomi T, Nakazawa C, *et al*. Monocyte chemoattractant protein 1 mediates retinal detachment-induced photoreceptor apoptosis. *Proc Natl Acad Sci USA* 2007;104:2425–2430.
- Porto A, Palumbo R, Pieroni M, *et al*. Smooth muscle cells in human atherosclerotic plaques secrete and proliferate in response to high mobility group box 1 protein. *FASEB J* 2006;20:2565–2566.
- Hisatomi T, Sakamoto T, Murata T, *et al*. Relocalization of apoptosis-inducing factor in photoreceptor apoptosis induced by retinal detachment *in vivo*. *Am J Pathol* 2001;158:1271–1278.
- Neekhra A, Luthra S, Chwa M, *et al*. Caspase-8, -12, and -3 activation by 7-ketocholesterol in retinal neurosensory cells. *Invest Ophthalmol Vis Sci* 2007;48:1362–1367.
- Biswas KK, Sarker KP, Abeyama K, *et al*. Membrane cholesterol but not putative receptors mediates anandamide-induced hepatocyte apoptosis. *Hepatology* 2003;38:1167–1177.
- Hoppe G, Rayborn ME, Sears JE. Diurnal rhythm of the chromatin protein Hmgb1 in rat photoreceptors is under circadian regulation. *J Comp Neurol* 2007;501:219–230.
- Hinton DR, He S, Graf K, *et al*. Mitogen-activated protein kinase activation mediates PDGF-directed migration of RPE cells. *Exp Cell Res* 1998;239:11–15.
- Han QH, Hui YN, Du HJ, *et al*. Migration of retinal pigment epithelial cells *in vitro* modulated by monocyte chemotactic protein-1: enhancement and inhibition. *Graefes Arch Clin Exp Ophthalmol* 2001;239:531–538.
- Glotin AL, Calipel A, Brossas JY, *et al*. Sustained versus transient ERK1/2 signaling underlies the anti- and proapoptotic effects of oxidative stress in human RPE cells. *Invest Ophthalmol Vis Sci* 2006;47:4614–4623.
- Klein JA, Ackerman SL. Oxidative stress, cell cycle, and neurodegeneration. *J Clin Invest* 2003;111:785–793.
- Tang D, Shi Y, Kang R, *et al*. Hydrogen peroxide stimulates macrophages and monocytes to actively release HMGB1. *J Leukoc Biol* 2007;81:741–747.
- Hollborn M, Francke M, Landiev I, *et al*. Early activation of inflammation- and immune response-related genes after experimental detachment of the porcine retina. *Invest Ophthalmol Vis Sci* 2008;49:1262–1273.
- Hisatomi T, Sakamoto T, Sonoda KH, *et al*. Clearance of apoptotic photoreceptors: elimination of apoptotic debris into the subretinal space and macrophage-mediated phagocytosis via phosphatidylserine receptor and integrin α v β 3. *Am J Pathol* 2003;162:1869–1879.
- Degrise B, Bonaldi T, Scaffidi P, *et al*. The high mobility group (HMG) boxes of the nuclear protein HMGB1 induce chemotaxis and cytoskeleton reorganization in rat smooth muscle cells. *J Cell Biol* 2001;152:1197–1206.
- Taniguchi N, Yoshida K, Ito T, *et al*. Stage-specific secretion of HMGB1 in cartilage regulates endochondral ossification. *Mol Cell Biol* 2007;27:5650–5663.
- Yamada Y, Ishibashi K, Ishibashi K, *et al*. The expression of advanced glycation endproduct receptors in rpe cells associated with basal deposits in human maculas. *Exp Eye Res* 2006;82:840–848.

36. Howes KA, Liu Y, Dunaief JL, *et al*. Receptor for advanced glycation end products and age-related macular degeneration. *Invest Ophthalmol Vis Sci* 2004;45:3713–3720.
37. Ma W, Lee SE, Guo J, *et al*. RAGE ligand upregulation of VEGF secretion in ARPE-19 cells. *Invest Ophthalmol Vis Sci* 2007;48:1355–1361.
38. Pachydaki SI, Tari SR, Lee SE, *et al*. Upregulation of RAGE and its ligands in proliferative retinal disease. *Exp Eye Res* 2006;82:807–815.
39. Elnor SG, Elnor VM, Jaffe GJ, *et al*. Cytokines in proliferative diabetic retinopathy and proliferative vitreoretinopathy. *Curr Eye Res* 1995;14:1045–1053.
40. Wang JB, Tian CW, Guo CM, *et al*. Increased levels of soluble syndecan-1 in the subretinal fluid and the vitreous of eyes with rhegmatogenous retinal detachment. *Curr Eye Res* 2008;33:101–107.
41. Barile GR, Pachydaki SI, Tari SR, *et al*. The RAGE axis in early diabetic retinopathy. *Invest Ophthalmol Vis Sci* 2005;46:2916–2924.
42. Matsushima K, Larsen CG, DuBois GC, *et al*. Purification and characterization of a novel monocyte chemotactic and activating factor produced by a human myelomonocytic cell line. *J Exp Med* 1989;169:1485–1490.
43. Pedrazzi M, Raiteri L, Bonanno G, *et al*. Stimulation of excitatory amino acid release from adult mouse brain glia subcellular particles by high mobility group box 1 protein. *J Neurochem* 2006;99:827–838.
44. Pastor JC, de la Rúa ER, Martín F. Proliferative vitreoretinopathy: risk factors and pathobiology. *Prog Retin Eye Res* 2002;21:127–144.
45. Straino S, Di Carlo A, Mangoni A, *et al*. High-mobility group box 1 protein in human and murine skin: involvement in wound healing. *J Invest Dermatol* 2008;128:1545–1553.
46. Lawrence MC, Jivan A, Shao C, *et al*. The roles of MAPKs in disease. *Cell Res* 2008;18:436–442.
47. Nakazawa T, Takeda M, Lewis GP, *et al*. Attenuated glial reactions and photoreceptor degeneration after retinal detachment in mice deficient in glial fibrillary acidic protein and vimentin. *Invest Ophthalmol Vis Sci* 2007;48:2760–2768.
48. Saika S. TGFbeta pathobiology in the eye. *Lab Invest* 2006;86:106–115.
49. Saika S, Yamanaka O, Nishikawa-Ishida I, *et al*. Effect of Smad7 gene overexpression on transforming growth factor beta-induced retinal pigment fibrosis in a proliferative vitreoretinopathy mouse model. *Arch Ophthalmol* 2007;125:647–654.
50. Saika S, Yamanaka O, Sumioka T, *et al*. Fibrotic disorders in the eye: targets of gene therapy. *Prog Retin Eye Res* 2008;27:177–196.
51. Bianchi ME, Manfredi AA. High-mobility group box 1 (HMGB1) protein at the crossroads between innate and adaptive immunity. *Immunol Rev* 2007;220:35–46.
52. Sha Y, Zmijewski J, Xu Z, *et al*. HMGB1 develops enhanced proinflammatory activity by binding to cytokines. *J Immunol* 2008;180:2531–2537.

マイクロアレイ・バイオチップの最新技術

Microarray Biochips

監修：伊藤嘉浩

Supervisor: Yoshihiro Ito

シーエムシー出版

第12章 糖鎖アレイ

隅田泰生*

1 はじめに

2~10個程度の糖分子から構成されるオリゴ糖鎖（以下、糖鎖）は様々な生理機能に関係しており、細胞の接着やシグナル伝達などには必須の役割を演じている¹⁾。糖鎖と蛋白質、細胞、ウイルスなどとの直接的な結合には、各々の糖鎖の特異的構造が重要であり、分子レベルでの解析には、構造明確な糖鎖を使用することが求められる。我々は、表面プラズモン共鳴（SPR）測定装置のセンサーチップとして、糖鎖を固定化した金チップ（シュガーチップと命名）を開発している²⁾。SPRは分子間相互作用を解析する技術として広く使用されている。簡単に原理を説明する。即ち、測定媒体である金属薄膜に光をある角度から入射させると、金属薄膜の表面の表面プラズモン波と金属薄膜に対して垂直方向のエバネッセント波が生じ、それらが共鳴する。この現象を表面プラズモン共鳴現象と称し、金属固有の誘電率や金属界面の屈折率の変化に影響されるので、反射光の強度あるいは表面プラズモン共鳴角（共鳴が起こるときの反射角の角度）の変化を測定することによって、界面で起こる変化を測定できる。従って、解析対象物を蛍光剤などのプローブ分子で化学修飾する必要がないため、相互作用解析が簡単に行え、化学修飾による解析対象物の変化（変性）を考慮する必要がない、さらにリアルタイムでの解析が可能となる。これらの利点から、生体分子のみならず、有機高分子や細胞の相互作用研究にも使用されている。このようなSPRと我々が開発したシュガーチップを組み合わせた分析法は、網羅的解析を可能とし、同時に新しい検査・診断法となる可能性を有している。

我々のシュガーチップに対する基本的コンセプトは、構造明確な糖鎖を金チップ上に固定化することであり、そのために我々はまず金チップと糖鎖とを結ぶリンカー化合物をデザインし、それと糖鎖とを複合体化した「糖鎖リガンド複合体」と称する化合物を合成した。このリガンド複合体の溶液を短時間金チップに接触させるだけで、Au-S結合を通して簡単に糖鎖を固定化したシュガーチップを調製できた。そこで、次に我々はこのリガンド複合体を多数（最大96個）固定化して、アレイタイプシュガーチップを調製し、それをSPRイメージング装置（東洋紡社製、

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Multi SPReiter) のセンサーチップとして用いて、検体 (蛋白質, 血清, ウイルス溶液など) の糖鎖結合性を迅速に測定する系を構築した。以下にいくつかの例を示す。なお, 本章で紹介するアレイタイプのシュガーチップおよび SPR イメージング法を用いた解析については, 弊社ホームページ (<http://www.sudxbiotec.jp/>) も参照されたい。

2 リガンド複合体の調製

我々が開発したモノバレントリンカー化合物を用いて, マルトース (Glc α 1-4 Glc) をリガンド複合体化した例を, 図 1 に示した。この際, マルトースの還元末端はその糖構造を消失するが, その部分は親水性のスペーサーとして作用するため, 疎水性のあるリンカー分子と測定対象の蛋白質との疎水性相互作用に基づく非特異的吸着を軽減する。このリガンド複合体 (Glc α 1-4 Glc-mono) を用いた SPR 測定例を図 2 に示す。ここでは, モリテックス社製の 2 チャンネル型機器である SPR-670 M を使用した。まず, センサーチップは以下のように調製した。すなわち Glc α 1-4 Glc-mono の 1 μ M 溶液 (メタノール/水=1/1, v/v) を調製し, そこに金蒸着チップ (スティックスバイオテック社製) を 2 時間から一晩浸漬し, その後浸漬した溶媒, 界面活性剤 (0.05 % Tween-20) 入り溶媒, リン酸バッファー等で洗浄した。洗浄の際は超音波洗浄機を用

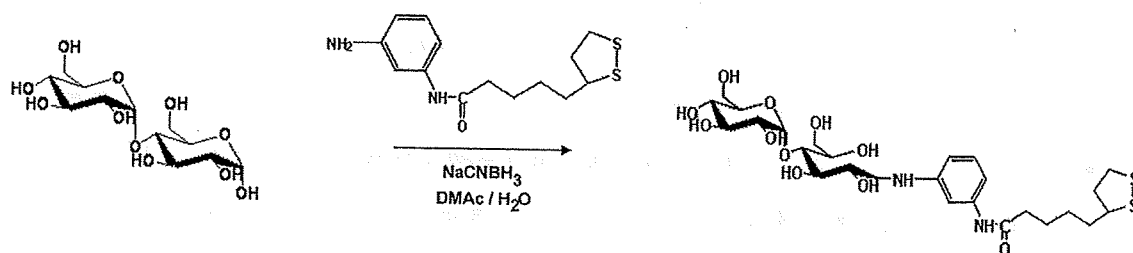


図 1 糖鎖リガンド複合体の調製例

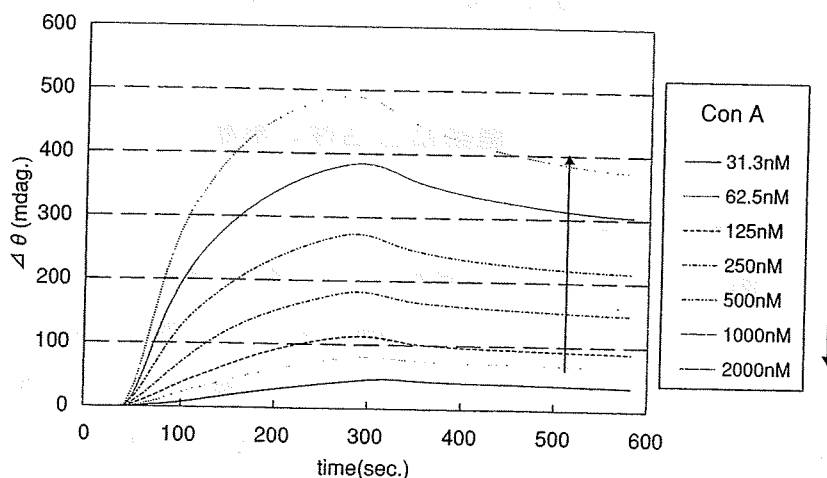


図 2 Glc α 1-4 Glc-mono チップへのコンカナバリン A の結合挙動 (SPR センサーグラム)

いて行い、固定化されていない糖鎖がチップ上に残存するのを防いだ。この方法によれば、同時に50枚以上のシュガーチップを調製することも可能であり、実験の再現性の確認時に問題となるチップロット間の差を無視することができる。このようにして調製したシュガーチップを用いて、 α グルコースに結合するレクチンとして知られるコンカナバリンA(Con A)の結合挙動を測定した。蛋白質濃度に依存してセンサーグラムが大きく観測されていることが分かる。なお、図2のデータは生データであり、対照を差し引いたものではない。一方、同じロットのチップを用いて、同じ条件でBSAの結合挙動を測定したところ、全く結合挙動は観測されなかった。以上から、我々の方法で固定化すると、非特異的相互作用を最小に抑え、かつ高選択的に糖鎖と蛋白質との相互作用が観測可能であることが明らかとなった。そこで、この系をアレイタイプのシュガーチップに適用することとし、70種類以上の糖鎖リガンド複合体を調製した。

3 アレイタイプのシュガーチップの調製とSPRイメージング

各々のリガンド複合体は500 μ M (0.5%のグリセロールを含む水溶液)に溶解し、その溶液1 μ lを専用チップ(東洋紡社製)上に、スポット装置(東洋紡社製)を用いてスポットした。スポットしたチップを室温で約1時間放置した後、水、リン酸緩衝液(pH 7.4, PBS), 0.05% Tween-20入りPBSで洗浄し、その後室温で乾燥させて保存した。このようにして、最大96種類の異なる糖鎖を固定化できるアレイタイプのチップを調製した。このチップをSPRイメージング装置(MultiSPRinterTM, 東洋紡社製)のプリズムにマッチングオイルを介して装着し、機器付属のマニュアルにしたがって種々の蛋白質の結合挙動を観測した。結果の一例を図3に示した。この実験では、蛋白質の濃度は2 μ M (PBS-T)、流速は100 μ l/minに固定している。それぞれの糖鎖に特異的に結合する蛋白質を簡単に判別できたことがわかった。さらに、図3の輝度を定量化することによって、結合の強度(親和性の強さ)を推定することもできた。

4 インフルエンザウイルスの糖鎖結合活性の解析

数年前に地球上に出現した強毒性のトリ型インフルエンザウイルス(H5N1)がヒト型に変異すると世界中に危機的流行が起こることは確実であり、簡便な検査法に基づく世界的な監視システムが必要である。インフルエンザウイルスは細胞表層のシアル酸含有糖鎖に結合し、そして細胞に侵入し感染することが知られている。また、ウイルスが結合するシアル酸含有糖鎖の構造は宿主の動物種によって異なり、さらに抗血清によって同じ亜型に分類されるウイルス株でも異なることが報告されている^{3~7)}。我々は、糖鎖を用いたウイルス株の検査・診断システムの構築

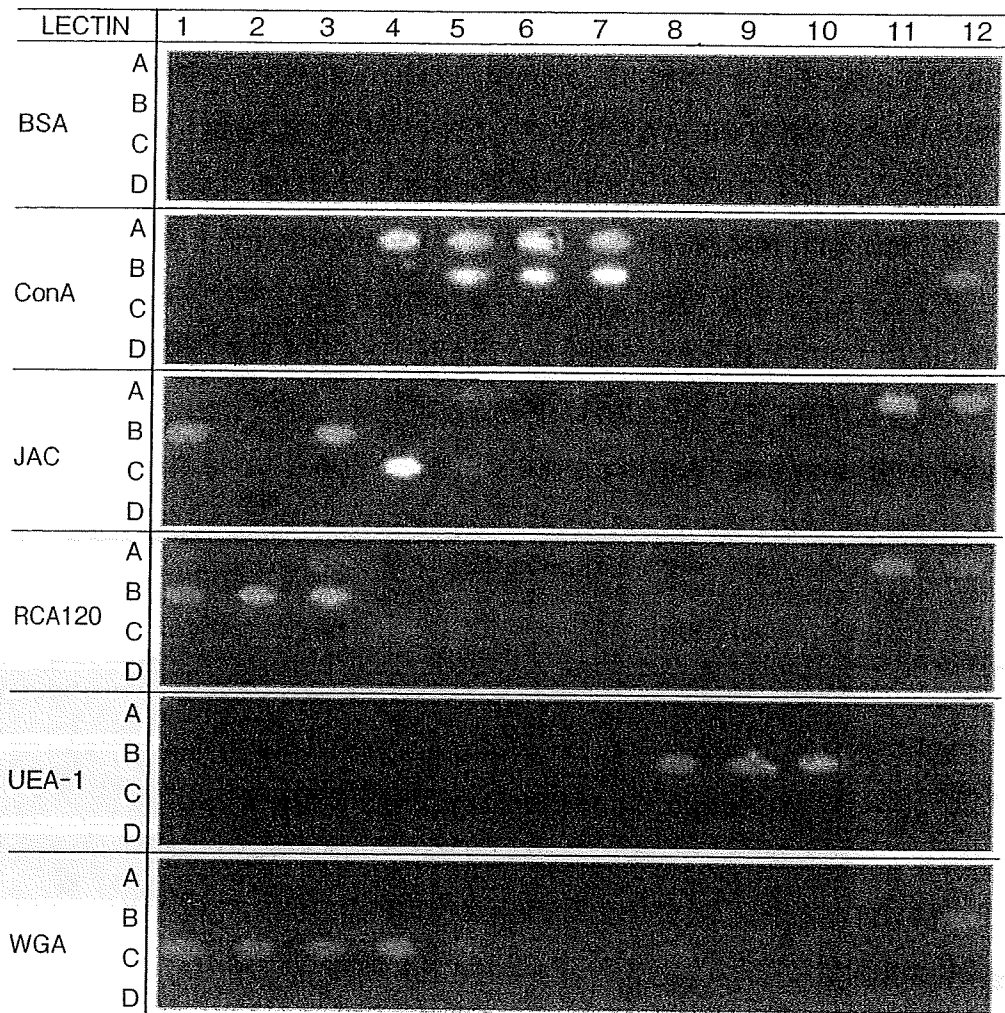


図3 アレイタイプのシュガーチップへの各種蛋白質の結合挙動 (SPR イメージング)
 蛋白質は牛血清アルブミン (BSA), コンカナバリン (ConA), *Jacalin lectin* (JAC), *Ricinus communis* アグルチニン (RCA 120), *Ulex europeas* アグルチニン (UEA-1), *Wheat germ* アグルチニン (WGA)。チップ上のアドレス (括弧内) にスポットした糖鎖リガンド複合体は以下の通り。Glc-mono (A 1); GlcNAc-mono (A 2); Gal-mono (A 3); Glc α 1-4 Glc-mono (A 4); Glc α 1-4 Glc α 1-4 Glc-mono (A 5); Glc α 1-6 Glc-mono (A 6); Glc α 1-6 Glc α 1-6 Glc-mono (A 7); Glc β 1-3 Glc β 1-3 Glc-mono (A 8); Glc β 1-4 Glc-mono (A 9); Glc β 1-6 Glc-mono (A 10); Gal α 1-6 Glc-mono (A 11); Gal α 1-4 Gal β 1-4 Glc-mono (A 12); Gal β 1-3 GalNAc α 1-6 Glc-mono (B 1); Gal β 1-4 GlcNAc β 1-6 Glc-mono (B 2); Gal β 1-4 Glc-mono (B 3); Gal β 1-4 [Fuc α 1-2] GlcNAc β 1-3 Gal β 1-4 Glc-mono (B 4); Man α 1-2 Man-mono (B 5); Man α 1-3 Man α 1-4 Man-mono (B 6); Man α 1-6 Man-mono (B 7); Fuc α 1-2 Gal β 1-4 Glc-mono (B 8); Fuc α 1-6 Glc-mono (B 9); Fuc β 1-6 Glc-mono (B 10); Xyl β 1-6 Glc-mono (B 11); GlcNAc α 1-6 Glc-mono (B 12); GlcNAc β 1-4 GlcNAc-mono (C 1); GlcNAc β 1-6 Glc-mono (C 2); GlcNAc β 1-3 Gal β 1-4 GlcNAc β 1-3 Gal β 1-4 Glc-mono (C 3); GalNAc α 1-6 Glc-mono (C 4); GalNAc β 1-3 Gal-mono (C 5); NeuAc α 2-3 Gal β 1-4 GlcNAc-mono (C 7); NeuAc α 2-3 Gal β 1-3 GlcNAc β 1-6 Glc-mono (C 8); NeuAc α 2-3 Gal β 1-4 GlcNAc β 1-6 Glc-mono (C 9); NeuAc α 2-6 Gal β 1-4 Glc-mono (C 10); NeuAc α 2-6 Gal β 1-3 GlcNAc β 1-6 Glc-mono (C 11); NeuAc α 2-3 Gal β 1-4 GlcNAc β 1-6 Glc-mono (C 12); GlcNS 6 S α 1-4 IdoA 2 S β 1-6 Glc-mono (D 1); Heparin-mono (D 2)。