Angiogenesis is the major feature in the pathogenesis of proliferative diabetic retinopathy (PDR).\(^1\) In this condition, retinal neovascularisation has a catastrophic effect on vision by causing vitreous haemorrhage, retinal detachment with formation of a fibrovascular membrane, and eventual blindness.\(^2\) The factors that stimulate the growth of retinal blood vessels have not been fully defined, but circumstantial evidence indicates that this not only involves angiogenic cytokines such as vascular endothelial growth factor (VEGF) but also vasoactive hormones such as angiotensin II.\(^3\) Angiotensin II has a proliferative effect and has been reported to regulate the growth of vascular smooth muscle cells\(^4\) and to stimulate the induction of various growth factors.\(^5\) Recent studies have suggested that abnormalities of the renin-angiotensin system (RAS) may also play a part in the progression of diabetic retinopathy.\(^6\) Inhibition of angiotensin converting enzyme (ACE) has been reported to be associated with a reduction of PDR,\(^7\) suggesting that suppression of the RAS may be of value for preventing and treating retinal neovascularisation. The hypothesis that an ocular RAS is involved in the development of PDR is supported by evidence that all components of the RAS are present in the retina\(^8\) and that angiotensin II, the effector molecule of this system, has angiogenic activity.\(^9\)

These findings prompted us to examine whether angiotensin II plays a part in the development of PDR in combination with VEGF, which is considered to be the most potent factor in promoting angiogenesis. Therefore, we investigated the relation between the levels of angiotensin II and VEGF in the vitreous fluid of diabetic patients as well as the correlation between these factors and the severity of PDR. The present study revealed that angiotensin II and VEGF levels in the vitreous fluid were correlated with the severity of PDR and that the vitreous levels of these two molecules were also correlated with each other. Furthermore, both angiotensin II and VEGF were elevated in the active stage of PDR. Angiotensin II may induce neovascularisation via a paracrine effect on VEGF in diabetic patients with PDR.

### MATERIALS AND METHODS

#### Patients

Undiluted vitreous fluid samples were harvested at the start of vitrectomy after informed consent was obtained from each subject following an explanation of the purpose and potential adverse effects of the procedure. This study was performed in accordance with the 1975 Declaration of Helsinki, as revised in 1983. Vitreous fluid samples were obtained from 51 patients with PDR, six diabetic patients without diabetic retinopathy, and 16 non-diabetic patients with ocular disease. Vitrectomy was performed on the 51 patients with PDR for the following reason: 27 had vitreous and/or preretinal haemorrhage, 17 had retinal detachment, and seven had macular heterotopia with proliferative tissues. The cases with macular heterotopia hoped to undergo the surgery because of the disturbed vision. The six diabetic patients without diabetic retinopathy included four with macular hole and two with epiretinal membrane, while the 16 non-diabetic patients included 12 with macular hole and four with epiretinal membrane (none of these 16 patients had proliferative vitreoretinopathy). Exclusion criteria for this study were: (1) treatment with an ACE inhibitor or an angiotensin II receptor antagonist (ARA), (2) treatment with an angiotensin II receptor antagonist; BRB, blood-retinal barrier; ELISA, enzyme linked immunosorbent assay; FAG, fluorescein angiography; KDR, kinase insert domain containing receptor; PDR, proliferative diabetic retinopathy; RIA, radioimmunoassay; RAS, renin-angiotensin system; VEGF, vascular endothelial growth factor.
plasma was rapidly frozen at −80°C. Those samples were obtained at the time of vitreoretinal surgery, with the protocol for sample collection being approved by the institutional review board and with all patients giving informed consent. Plasma samples were also collected from the 51 patients with PDR. Blood was immediately placed on ice and subjected to centrifugation at 3000 × g for 5 minutes at 4°C, after which the plasma was rapidly frozen at −80°C until assay. The institutional review board also approved the protocol for blood collection.

**Sample collection**

Samples of vitreous fluid were collected into sterile tubes and were rapidly frozen at −80°C. Those samples were obtained at the time of vitreoretinal surgery, with the protocol for sample collection being approved by the institutional review board and with all patients giving informed consent.

**Measurement of VEGF, angiotensin II, and ACE levels**

Both VEGF and angiotensin II were measured in vitreous samples from the same eye as well as in the plasma. The VEGF concentration was measured by an enzyme linked immunosorbent assay (ELISA) for human VEGF (R&D Systems, Minneapolis, MN, USA). This VEGF kit was able to detect two of the four VEGF isoforms (VEGF121 and VEGF165), probably because these two shorter VEGF isoforms are secreted and the two longer isoforms are cell associated. The assay was performed according to the manufacturer's instructions. A standard solution (100 µl) or sample (10 or 100 µl) was added to the wells of a 96 well plate coated with an immobilised monoclonal antibody. After incubation, the plate was washed and the enzyme labelled antibody was added. After further incubation, the plate was washed again and the substrate was added. The reaction was stopped after colour had developed by adding the stop solution, and the optical density was determined at 450 and 620 nm using an absorption spectrophotometer (Titertek Multispec MCC/340; ICN, Tokyo, Japan). A standard curve was plotted from the measurements made with the standard solution (from 15.6 to 1000 pg/ml), and the concentration of VEGF in each sample was determined from this curve. The VEGF levels in vitreous fluid and plasma were within the detection range of the assay, since the minimum detectable concentration was 15.6 pg/ml (coefficient of variation (CV) intra-assay 3.5%, CV interassay 5.8%).

Vitreous and plasma angiotensin II levels were determined by radioimmunoassay (RIA) and serum ACE levels were determined by the method of Kasahara. For the measurement of angiotensin II, 0.5 ml of vitreous fluid or plasma was mixed with 2.5 ml of ethanol. After centrifugation at 2000 g for 15 minutes at 4°C, the supernatant was dried under nitrogen gas at 37°C. The dried samples were reconstituted with 0.5 ml of assay buffer, and assay was performed with an angiotensin II RIA kit (Nichols, CA, USA). Measurement of ACE activity was performed with an ACE colour kit (Fujirebio, Tokyo, Japan). Serum (0.05 ml) was mixed with 0.5 ml of p-hydroxybenzoyl-glycyl-l-histidyl-l-leucine. After incubation, the reaction was stopped when colour had developed by adding the stop solution and the optical density was determined at 505 nm using an absorption spectrophotometer (AU600; Olympus, Tokyo, Japan). The angiotensin II and ACE levels in vitreous fluid and plasma were within the detection range of these assays, since the minimum detectable concentration was 0.4 pg/ml (CV intra-assay 3.8%, CV interassay 6.0%) and 2.5 pg/ml (CV intra-assay 4.0%, CV interassay 6.2%), respectively.

**Statistical analysis**

All analyses were performed with SAS System 6.12 software (SAS Institute Inc, Cary, NC, USA). Data are presented as the frequency or mean (SD). Data with a skewed distribution were transformed to a logarithmic scale, and the geometric mean was calculated together with 1 SD below and 1 SD above the mean on that scale. Analysis of variance (ANOVA) was used to test for statistically significant differences among the groups and the Turkey-Kramer multiple comparison test was also applied when appropriate. Correlations were tested using Spearman's rank correlation coefficients. A two tailed p value of less than 0.05 was considered to indicate statistical significance.

**RESULTS**

**Vitreous levels of VEGF and angiotensin II**

The diabetic patients included 31 men and 26 women mean age 60.7 (SD 10.5) years, with a diabetes duration of 16.2 (6.3) years for the measure-
The vitreous fluid concentration of VEGF was significantly higher (p<0.0001) in the patients with PDR (1135.2 pg/ml (75.6 to 3280.0)) in the PDR patients (p =0.0106) (Table 1). Plasma angiotensin II levels showed a significant correlation with the vitreous fluid levels of both VEGF and angiotensin II (p=0.596, p<0.0001 and p=0.755, p<0.0001, respectively). The plasma ACE level (14.2 pg/ml (2.5 to 26.0)) was significantly correlated with the vitreous fluid level of angiotensin II (p=0.372, p=0.0013), but was not significantly correlated with that of VEGF (p=0.223, p=0.0594). There was no significant relation between plasma and vitreous fluid VEGF levels (p=0.128, p=0.1490). There was also no significant relation between HbA1c (7.6 % (4.8 to 12.3)) and the vitreous levels of VEGF or angiotensin II (p=0.220, p=0.1712 and p=0.253, p=0.0626, respectively).

**DISCUSSION**

The present study showed that both angiotensin II and VEGF levels were increased in the vitreous fluid of patients with PDR and were correlated with the severity of diabetic retinopathy. In addition, angiotensin II and VEGF showed a statistically significant correlation with each other and the vitreous fluid level of angiotensin II was elevated in the active stage of PDR. We showed that not only the vitreous level of VEGF but also that of angiotensin II was significantly elevated in PDR patients when compared with non-diabetic patients or diabetic patients without retinopathy. Angiotensin II has been shown to promote the growth of capillary vessels in the chorioallantoic membrane\(^6\) and to stimulate new vessel formation in the rabbit cornea.\(^7\) A protective effect of an ACE inhibitor and of an ARA AT1 receptor on hyperoxia induced and normoxia induced neovascularisation has been demonstrated in newborn mice.\(^8\) However, continuous transvitreal infusion of angiotensin II alone produced retinal artery constriction, but not new vessel formation from the retina to the vitreous in the cat eye.\(^9\) Angiotensin II not only has a growth promoting effect, but also stimulates the induction of many cytokines and growth factors.\(^10\) Therefore, angiotensin II may affect neovascularisation in combination with other cytokines or growth factors.

**Vitreous and plasma levels of VEGF, angiotensin II, and ACE**

The vitreous fluid concentration of VEGF was significantly higher than the plasma VEGF level (50.9 pg/ml (15.6 to 396.0)) in the patients with PDR (p<0.0001) (Table 1). The vitreous fluid concentration of angiotensin II was also significantly higher than the plasma angiotensin II level (17.5 pg/ml (4.0 to 46.0)) in the PDR patients (p =0.0106) (Table 1).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Comparison of VEGF and angiotensin II concentrations in vitreous fluid and plasma in diabetic patients with PDR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vitreous fluid</td>
</tr>
<tr>
<td>VEGF</td>
<td>1135.2 (837.7)</td>
</tr>
<tr>
<td>Angiotensin II</td>
<td>25.0 (14.3)</td>
</tr>
</tbody>
</table>

*Figure 2* Relation between the vitreous fluid levels of VEGF and angiotensin II in PDR patients and diabetic patients without retinopathy (p=0.702, p<0.0001).

*Figure 3* (A) VEGF levels in the vitreous fluid of patients with active PDR and quiescent PDR (*p<0.0001*). (B) Angiotensin II levels in the vitreous fluid of patients with active PDR and quiescent PDR (*p=0.0005*).
In the present study, the vitreous level of angiotensin II was statistically correlated with that of VEGF. It has been suggested that induction of VEGF mRNA most probably occurs through transcriptional regulation. Receptors for angiotensin II are present on endothelial cells, and angiotensin II acts to stimulate endothelial cell growth and upregulate VEGF mRNA expression. Moreover, angiotensin II may potentiate VEGF induced angiogenic activity in the retina through increased expression of the VEGF receptor Flk-1/KDR. The effect of angiotensin II on VEGF expression was completely inhibited by an ARA. There is a possibility that angiotensin II might influence VEGF elicited signal transduction or post-transcriptional regulation of KDR. The functioning of the ocular RAS is not yet clear. However, our recent previous studies have suggested that an autocrine-paracrine relation may exist between angiotensin II and VEGF in ocular tissues. The capacity of VEGF to act as a potent angiogenic agent suggests that an angiotensin II induced increase of VEGF production could have a key role in the occurrence of neovascularisation in PDR. Further investigations will be needed to clarify the ocular interactions between angiotensin II and VEGF as well as the role of angiotensin II during neovascularisation in PDR.

It seems logical for the vitreous fluid levels of angiotensin II and VEGF to vary with the severity of PDR. In fact, we found that the vitreous fluid levels of both angiotensin II and VEGF were significantly higher in active PDR than in quiescent PDR. The levels of both angiotensin II and VEGF in the vitreous fluid seem to increase during active neovascularisation and to decrease in the absence of neovascularisation, because we classified the severity of PDR according to the activity of neovascularisation in this study. It was previously reported that the vitreous fluid level of VEGF was higher in active PDR than in quiescent PDR and that VEGF played a major part in maintaining and stimulating intraretinal neovascularisation in diabetic retinopathy. However, to our knowledge, the present study provides the first evidence that the vitreous fluid levels of angiotensin II are elevated in the active stage of PDR.

It is still unclear whether production of angiotensin II can occur in ocular tissues. From our results, it cannot be said whether ocular angiotensin II is located intracellularly or extracellularly and it is also impossible to determine whether angiotensin II is synthesised locally in the eye or sequestered from the plasma. Sequestration is not very likely since that would imply a specific uptake process. The local concentration of angiotensin II in the retinal microvasculature is reported to be higher than the serum and vitreous fluid levels. 1, 9 In the present study, the vitreous fluid level of angiotensin II was significantly higher than the plasma level, but the statistical difference was small. Furthermore, the plasma levels of angiotensin II and ACE were significantly correlated with the vitreous fluid level of angiotensin II. The level of angiotensin II in the vitreous fluid from normal porcine eyes is low to undetectable, in contrast with the relatively high levels in surrounding ocular tissues such as the RPE and choroid. 9 Breakdown of the blood-retinal barrier (BRB) may facilitate diffusion of angiotensin II from the blood into the vitreous fluid. Since the vitreous can be considered the repository for products originating from the retina, a high level of angiotensin II might well be explained by its production and secretion from the retina. Accordingly, angiotensin II may be produced locally in ocular tissues, but little of this angiotensin II may leak into the ocular fluid under normal conditions and only when the BRB is disrupted will angiotensin II reach the vitreous fluid in high concentrations. The patients with active PDR in the present study had a hyperfluorescens pattern on FAG just before surgery. These results and previous reports suggest that disruption of the BRB may lead to elevation of the vitreous fluid concentration of angiotensin II. ACE inhibitors have been reported to maintain the BRB in diabetic patients and to have a favourable effect on diabetic retinopathy. 1, 3 It may be possible that angiotensin II in the vitreous fluids derived both from production in ocular tissues (such as the retinal pigment epithelium-chorioid complex) and via disruption of the BRB.

The underlying biochemical cause of PDR would seem to be chronic hyperglycaemia, suggesting that HbA1c might show a positive relation with the angiotensin II concentration in vitreous fluid. However, there was no significant correlation between them in the present study. The VEGF concentration also showed no significant relation with the HbA1c value. Because glycaemic control was improved in some patients before vitreous surgery, the HbA1c level at the time of the operation did not necessarily indicate their long term glycaemic control, so we could not assess the relation of hyperglycaemia to angiotensin II or VEGF based on these results.

In summary, the present study showed that the concentration of both angiotensin II and VEGF in the vitreous fluid of patients with PDR were significantly higher than those in non-diabetic patients or diabetic patients without retinopathy. Vitreous fluid levels of angiotensin II were significantly correlated with those of VEGF. Moreover, the levels of both VEGF and angiotensin II were higher in active PDR than in quiescent PDR. These findings support our contention that angiotensin II plays a part in the neovascularisation process of PDR via stimulation of VEGF. The therapeutic implications are that inhibition of the RAS may be beneficial for the treatment of PDR. Indeed, the beneficial effects of ACE inhibition for patients with PDR have recently been shown by the EUCLID study 13 and the Steno study. 14 Our results support the possibility that the treatment with an ACE inhibitor or ARA may effectively prevent the development of PDR. We hope to investigate the possibility that ACE inhibitor or ARA inhibit angiotensin II in eyes and also inhibit the progression of retinopathy to PDR in the next stage.

ACKNOWLEDGEMENTS

This study was supported by Health Science Research Grants (No 10060101, to HF, HY, and SH) from the Ministry of Health and Welfare, Research on Eye and Ear Sciences, Immunology, Allergy and Organ Transplantation in Japan.

We thank Drs Shigehiko Kitano, Erika Shimizu, Kensuke Haruyama, and Shinko Nakamura for their assistance in collecting the vitreous and plasma samples and in performing the ophthalmological examinations. We also thank Drs Yasuhiko Iwamoto and Naoko Iwashita for their assistance in performing the internal medical examinations. We finally would like to thank Katsunori Shimada for his assistance in conducting the statistical analyses.

Authors’ affiliations

H Funatsu, Y Nakashisi, Department of Ophthalmology, Diabetes Center, Tokyo Women’s Medical University

H Yamashito, Department of Ophthalmology, Yamagata University, School of Medicine

S Hori, Department of Ophthalmology, Tokyo Women’s Medical University

REFERENCES


Angiotensin II and VEGF in vitreous fluid