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Endothelial Dysfunction Precedes Development of Microalbuminuria in IDDM

Coen D.A. Stehouwer, H.R. Andreas Fischer, Arno W.R. van Kuijk, Bettine C.P. Polak, and Ab J.M. Donker

In patients with insulin-dependent diabetes mellitus (IDDM), microalbuminuria is a predictor of widespread severe microangiopathy and macroangiopathy. Patients with microalbuminuria show generalized dysfunction of the vascular endothelium, but it is unknown whether endothelial dysfunction precedes the development of microalbuminuria. We examined a cohort of 17 IDDM patients at baseline and on three occasions during a follow-up of (median) 64 months (range 51–89). All had normal (<15 μg/min) urinary albumin excretion (UAE) at the first three examinations. At the fourth examination, 11 patients had normal UAE and 6 had microalbuminuria (median 25.7 μg/min [range 15.3–42.8]). Compared with patients with normal UAE, microalbuminuric patients had significantly higher plasma levels of von Willebrand factor (vWF), a marker of endothelial dysfunction, at the second (200% [118–274] vs. 131% [69–186]), third (208% [188–270] vs. 125% [82–190]), and fourth examinations (231% [202–269] vs. 132% [88–208], P < 0.0001), but not at baseline (128% [98–161] vs. 122%). An increase in vWF preceded the occurrence of microalbuminuria by ~3 years. The groups did not differ with regard to age, diabetes duration, blood pressure, mean glycated hemoglobin and cholesterol, smoking habits, or extent of retinopathy. Endothelial dysfunction, as estimated by plasma vWF concentration, preceded and may predict the development of microalbuminuria in IDDM. Diabetes 44:561–564, 1995

RESEARCH DESIGN AND METHODS

Cohort study. Between June 1985 and August 1988, 65 IDDM patients (fasting C-peptide levels < 0.01 nmol/l) were recruited and gave informed consent, as previously reported (11,12). Clinical and laboratory data, as detailed below, were obtained at baseline (first examination) and after a median follow-up of 3 years (second examination). This study was completed in 59 patients and showed that the development of microalbuminuria was paralleled by increases in the plasma vWF concentration, but we could not determine whether such increases preceded the occurrence of microalbuminuria (11). To further investigate the time course of the development of complications of diabetes in relation to changes in vWF, patients were invited for further follow-up examinations when, at the second examination, they had normal UAE, no diabetic retinopathy on ophtalmoscopy, and fair glycemic control (HbA1c < 8.5%) and used no medication other than insulin (12). Patients with poorly controlled diabetes were excluded to avoid, as much as possible, fluctuations of plasma vWF concentrations associated with short-term changes in glycemic control (18). Seventeen patients fulfilled these criteria and underwent third and fourth examinations, which are the subjects of this report. The median follow-up in these patients was 24 months (range 11–47), 40 months (27–64), and 64 months (51–89) between the first and the second, the first and the third, and the first and the fourth examinations, respectively.

Clinical and laboratory studies. Detailed descriptions are given elsewhere (11,12,17). At each examination, we recorded age, diabetes duration, body mass index (BMI), blood pressure (BP), diastolic phase V, to the nearest 5 mmHg; twice, after 15 min of supine rest, using a

standard sphygmomanometer with an appropriately sized cuff), insulin
dose, current smoking habits, and current medication. After an over­
night fast, blood was drawn from an antecubital vein for measurement of
plasma vWF was thus reduced to — 10% . Patients were instructed to avoid strenuous exercise and to empty their
bladders completely on arising and at noon. Completeness of urine
was defined (in advance [11,12]) as UAE of 15-200 µg/min. (We chose 15
µg/min as cutoff because the median UAE in healthy volunteers in our
laboratory is 5.7 µg/min, with >95% having an UAE <15 µg/min [11].)
Plasma vWF was measured by immuno­electrophoresis (11). The intra-assay and inter­assay
variations were 4.1 and 8.7%, respectively; the same assay was used
 throughout the study. Levels of and changes in vWF were expressed as
percentages of normal pooled plasma, the antigen level of which is
50-150% (0.50-1.50 IU/ml).

Main outcome measures
UAE. On the basis of the median UAE in at least three consecutive 4-h
(0800-1200) urine collections, patients were classified as having normal
(<15 µg/min) or increased UAE. Note that median values are reported, which
minimizes the influence of occasional outliers. Microalbuminuria was
defined (in advance [11,12]) as UAE of 15-200 µg/min. (We chose 15
µg/min as cutoff because the median UAE in healthy volunteers in our
laboratory is 5.7 µg/min, with >95% having an UAE <15 µg/min [11].)

Endothelial function. Plasma vWF antigen concentration was mea­sured by
immuno­electrophoresis (11). The intra­assay and inter­assay
variations were 4.1 and 8.7%, respectively; the same assay was used
throughout the study. Levels of and changes in vWF were expressed as
percentages of normal pooled plasma, the antigen level of which is
50-150% (0.50-1.50 IU/ml).

RESULTS

All 17 patients completed the study, except 1 refused fluo­rescein angiography at the third examination and another
decided both ophthalmoscopy and angiography at the fourth.
There was no clinical evidence of macrovacular
complications in any patient at the third examination, but at
the fourth, one patient (with normal UAE) had had a stroke, as
confirmed by chart review. There were only two smokers
among the patients; this factor was therefore omitted from
further analyses. In one patient with persistently normal
UAE, antihypertensive medication (a β-receptor antagonist)
was started between the third and fourth examinations.

UAE. At the fourth examination, 11 patients had normal UAE
(7.2 [3.1-9.9] µg/min) and 6 had microalbuminuria (25.7
[15.3-42.8] µg/min) (Fig. 1). Thus, the cumulative incidence
of microalbuminuria was 30%, yielding an incidence density
(cases per 100 person­years of follow­up) of 6.3. The main
difference between the groups with normal versus increased

UAE was the plasma vWF concentration (Table 1 and Fig. 1),
which was higher in the microalbuminuric patients at the
second (median 200% [range 108-274] vs. 131% [69-180]),
third (208% [188-270] vs. 125% [82-190]), and fourth exami­nations (231% [202-269] vs. 132% [88-208]), P < 0.0001 by
analysis of variance [ANOVA] and by Student's t tests), but
not at baseline (128% [98-161] vs. 123% [87-210]). UAE at the
fourth examination was related to both the plasma vWF level
(r = 0.70, P = 0.002) and the change in plasma vWF between
examinations 1 and 4 (r = 0.80, P < 0.0001). A plasma vWF
level above the upper limit of normal (i.e., 150%) at two or
more of the first three examinations predicted the presence
of microalbuminuria at the fourth examination with 100%
sensitivity (6 of 6) and 82% specificity (9 of 11). These results
were not materially altered by exclusion of the patient who
received antihypertensive treatment or by exclusion of the
two smokers.

FIG. 1. Time course of UAE and plasma vWF in patients with normal
UAE (*) and microalbuminuria (●) at the final follow­up. A: scattergram
of UAE (*) and medians of vWF (*— — and ●— ●). B: vWF
(normal range 50-150% [0.50-1.50 IU/ml]).
TABLE 1
Clinical and laboratory data for patients with IDDM

<table>
<thead>
<tr>
<th></th>
<th>Normal UAE</th>
<th>Microalbuminuria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (M/W)</td>
<td>5/6</td>
<td>3/3</td>
</tr>
<tr>
<td>Age (years)</td>
<td>40 ± 13</td>
<td>47 ± 19</td>
</tr>
<tr>
<td>Diabetes duration (years)</td>
<td>16 ± 3</td>
<td>14 ± 9</td>
</tr>
<tr>
<td>Follow-up duration (months)</td>
<td>64 (51–85)</td>
<td>67 (54–89)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.5 ± 3.2</td>
<td>23.8 ± 2.4</td>
</tr>
<tr>
<td>Smoker (yes/no)</td>
<td>1/10</td>
<td>1/6</td>
</tr>
<tr>
<td>Blood pressure (mmHg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First examination</td>
<td>139/84 ± 24/6</td>
<td>140/83 ± 28/15</td>
</tr>
<tr>
<td>Second examination</td>
<td>132/81 ± 10/6</td>
<td>142/85 ± 21/10</td>
</tr>
<tr>
<td>Third examination</td>
<td>135/83 ± 15/4</td>
<td>145/85 ± 15/9</td>
</tr>
<tr>
<td>Fourth examination</td>
<td>140/83 ± 25/7</td>
<td>140/83 ± 16/5</td>
</tr>
<tr>
<td>Mean</td>
<td>138/83 ± 19/4</td>
<td>140/84 ± 19/8</td>
</tr>
<tr>
<td>Serum total cholesterol (mmol/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First/second examination</td>
<td>6.2 ± 0.8/6.3 ± 0.7</td>
<td>6.0 ± 0.8/6.1 ± 0.7</td>
</tr>
<tr>
<td>Third/fourth examination</td>
<td>6.1 ± 0.7/6.5 ± 1.3</td>
<td>5.9 ± 0.7/6.8 ± 0.8</td>
</tr>
<tr>
<td>Glycated hemoglobin (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First/second examination</td>
<td>8.0 ± 1.0/6.9 ± 0.8</td>
<td>8.4 ± 1.3/6.8 ± 1.3</td>
</tr>
<tr>
<td>Third/fourth examination</td>
<td>6.7 ± 0.8/7.5 ± 1.9</td>
<td>6.7 ± 1.0/6.6 ± 0.7</td>
</tr>
<tr>
<td>Mean</td>
<td>7.2 ± 0.9</td>
<td>7.0 ± 0.9</td>
</tr>
<tr>
<td>Serum creatinine (mmol/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First/second examination</td>
<td>80 ± 7</td>
<td>77 ± 8</td>
</tr>
<tr>
<td>Third/fourth examination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetic retinopathy (yes/no)</td>
<td>4/7</td>
<td>3/2</td>
</tr>
<tr>
<td>Fundoscopy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluorescein angiography</td>
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</tbody>
</table>

Data are number of patients, means ± SD, or medians (ranges) at the fourth examination.

Retinopathy. At the fourth examination, retinopathy was absent on fundoscopy in nine patients and present in seven. When angiography, a more sensitive method, was used as the criterion, retinopathy was absent in 5 patients and present in 11. Retinopathy was mild and consisted of microaneurysms (in nine patients), small hemorrhages (in five patients), and dilated capillaries (in seven patients; angiographic data). No patient had proliferative changes. Patients in whom retinopathy was absent on fundoscopy did not differ from those in whom it was present with regard to follow-up duration, sex distribution, age, diabetes duration, BMI, or serum creatinine at the fourth examination. In addition, ANOVA indicated no differences, at examinations 1–4, in UAE, glycated hemoglobin, serum cholesterol, or systolic and diastolic BP. Plasma vWF was also similar (124% [99–210] vs. 122% [87–170], 139% [101–200] vs. 145% [93–274], 140% [102–210] vs. 140% [82–270], and 139% [112–237] vs. 139% [88–209], respectively). Analysis of the angiographic data yielded similar results.

vWF. vWF and the change in vWF were related to UAE (see above) but not to potential determinants of endothelial injury, such as age, diabetes duration, glycated hemoglobin, BP, and serum cholesterol. Similarly, vWF was not related to the blood glucose concentration at the time of blood sampling, which varied between 3.6 and 16.9 mmol/l.

DISCUSSION
This study supports the hypothesis that the vascular endothelium is an early and relevant target in the pathogenesis of diabetic microangiopathy. Endothelial dysfunction, as estimated by plasma vWF concentration, preceded the development of microalbuminuria in IDDM by as much as 3 years. In accordance with an earlier report (12), vWF levels were not related to the development of early diabetic retinopathy, which suggests that retinal endothelial injury is not accompanied by widespread endothelial dysfunction resulting in increases in vWF.

Endothelial dysfunction in microalbuminuric IDDM appears to be generalized in that it affects many aspects of endothelial function (1,3,7,9–11,13). In IDDM patients with normal UAE, however, endothelial dysfunction is more variable, restricted in nature, and less severe (13). As a working hypothesis, we suggest that endothelial dysfunction in IDDM develops gradually, with sustained increases in plasma vWF and UAE as relatively advanced features.

The type of endothelial dysfunction reflected by increased vWF levels is particularly closely related to microalbuminuria not only in IDDM (11), but also in non-insulin-dependent diabetes mellitus (NIDDM) (13,17) and essential hypertension (18). Microalbuminuria reflects an increased transcapillary passage of macromolecules (1), a phase that, in IDDM, is preceded by a clear and persistent increase in vWF levels, as shown by our study. Such data are not available for NIDDM or hypertension, although high vWF levels in NIDDM may similarly increase the risk of development of microalbuminuria and the risk of clinical cardiovascular disease once microalbuminuria is present (17). It is not clear, however, whether the prognostic value of vWF is related to its specific functions, i.e., enhancement of platelet adhesion and factor VIII availability, or whether it is simply a marker of endothelial injury and dysfunction. Nevertheless, both UAE and vWF deserve consideration as clinically useful markers of vascular status.

Determinants of increases in vWF, i.e., of endothelial injury, were not identified. Increases in vWF are nonspecific with respect to the type of injury and can be induced by hypertension, smoking, hypercholesterolemia, hyperglycemia, activation of coagulation, and cytokines (13,18,19). The pathogenesis of microalbuminuria is likely to involve hyperglycemia and an early rise in BP (1,3,20–22). Our study was small and excluded patients with poor glycemic control, thereby limiting the ability to find a relation between UAE or vWF and glycated hemoglobin (11) or BP (20–22). In addition, susceptibility to the development of diabetic nephropathy (and presumably microalbuminuria) is thought to vary...
among individuals (23). Variability among individuals in the susceptibility to injury of the endothelium might play a role, and this would hamper the identification of determinants of endothelial injury in cohort studies. Finally, other factors not assessed in this study may be important, such as insulin resistance, hyperinsulinemia, dyslipidemia, and activation of coagulation (19,24–26).

Are our findings generalizable? Clearly, selection bias cannot be completely excluded in a small study such as this. On the other hand, the patients were not selected on the basis of plasma vWF; therefore, the relationship between UAE and vWF is unlikely to have been affected by selection bias. In addition, the incidence density of microalbuminuria observed (6.3 or 4.2 [4 of 17; Fig. 1] with 20 μg/min [1,3,22] instead of 15 μg/min as cutoff) is within the range reported by others (1.1–8.2 [20–22,27–31]). Finally, the exclusion of patients with poor glycemic control may have increased the within-person stability of plasma vWF levels. Thus, the applicability of our results to patients with poorly controlled diabetes is somewhat uncertain.

Nevertheless, a sustained increase in plasma vWF in patients with IDDM is associated with a high risk of development of microalbuminuria. We suggest that such patients are candidates for intensified treatment of hyperglycemia and of rises in BP (even small ones).

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