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Plasma Metanephrines in the Diagnosis of Pheochromocytoma

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Objective: To examine whether tests for plasma metanephrines, the o-methylated metabolites of catecholamines, offer advantages for diagnosis of a pheochromocytoma over standard tests for plasma catecholamines or urinary metanephrines.

Design: Cross-sectional study.

Setting: 3 clinical specialist centers.

Patients: 52 patients with a pheochromocytoma; 67 normotensive persons and 51 patients with essential hypertension who provided reference values; and 23 patients with secondary hypertension and 50 patients with either heart failure or angina pectoris who served as comparison groups.

Measurements: Plasma concentrations of catecholamines (norepinephrine and epinephrine) and metanephrines (normetanephrine and metanephrine) were measured in all patients. The 24-hour urinary excretion of metanephrines was measured in 46 patients with pheochromocytoma.

Results: Pheochromocytomas were associated with increases in plasma concentrations of metanephrines that were greater and more consistent than those in plasma catecholamine concentrations. No patient with a pheochromocytoma had normal plasma concentrations of both normetanephrine and metanephrine. The sensitivity of these tests was 100% (52 of 52 patients [95% CI, 94% to 100%]), and the negative predictive value of normal plasma concentrations of metanephrines was 100% (162 of 162 patients). Tests for plasma catecholamines yielded eight false-negative results and a sensitivity of 85% (44 of 52 patients [CI, 72% to 93%]). The negative predictive value of normal plasma concentrations of catecholamines was 95% (156 of 164 patients). Tests for urinary metanephrines yielded five false-negative results and a sensitivity of 89% (41 of 46 patients [CI, 76% to 96%]). Because no statistical difference was noted in the number of false-positive results between tests for plasma metanephrines (15%) and tests for plasma catecholamines (18%), the specificities of the two tests did not differ.

Conclusions: Normal plasma concentrations of metanephrines exclude the diagnosis of pheochromocytoma, whereas normal plasma concentrations of catecholamines and normal urinary excretion of metanephrines do not. Tests for plasma metanephrines are more sensitive than tests for plasma catecholamines or urinary metanephrines for the diagnosis of pheochromocytoma.

Pheochromocytoma is a tumor of chromaffin cells that usually presents as hypertension. The tumor has potentially life-threatening consequences if it is not promptly diagnosed, located, and removed. Evidence of excessive production of catecholamines is essential for diagnosis of the tumor. Traditional tests have relied on measurements of the 24-hour urinary excretion of catecholamines (norepinephrine and epinephrine) or of the products of catecholamine metabolism (1-4).

Because of the common problems of incompleteness and inconvenience associated with 24-hour urine collections, clinicians have long sought a diagnostic test based on sampling of antecubital venous blood. Measurements of plasma catecholamines are useful in this respect (4, 5). However, patients with a pheochromocytoma can have plasma concentrations of catecholamines that fall within the range of those in patients with essential hypertension (4, 6) (that is, false-negative results). In addition, emotional distress or pathologic conditions other than pheochromocytoma (such as heart failure) can produce abnormally high catecholamine concentrations (7, 8) (that is, false-positive results). Glucagon stimulation and clonidine suppression testing can enhance the accuracy of plasma catecholamine determinations in the diagnosis of pheochromocytoma (9, 10). These tests, however, can still yield false-negative or false-positive results (9-11); they also require considerable time and effort. The search has continued for a single simple, highly sensitive and specific blood test with which to confirm the presence of the tumor in patients with pheochromocytoma. We studied the diagnostic accuracy of tests for specific catecholamine metabolites for this purpose, notably the metanephrines—normetanephrine and metanephrine.

An understanding of why plasma metanephrines may be particularly useful for diagnosis of pheochromocytoma requires an understanding of catecholamine metabolism. Norepinephrine and epinephrine are first metabolized intraneuronally by deamination to dihydroxyphenylglycol or extraneuronally by o-methylation to the metanephrines (12). Because most dihydroxyphenylglycol is formed from norepinephrine leaking from neuronal stores and little is formed from circulating catecholamines (13, 14), plasma levels of this metabolite are relatively insensitive to the release of catecholamines into the circulation from a pheochromocytoma (6, 15). The formation of most methoxyhydroxyphenylglycol from dihydroxyphenylglycol (14) and the formation of most vanillylmandelic acid from methoxyhydroxyphenylglycol within the liver (16) explains
why a test for vanillylmandelic acid is also a poorer marker for pheochromocytoma than other tests (17). In contrast, preferential metabolism of circulating catecholamines compared with neuronal catecholamines by extraneuronal pathways (14) suggests that the metanephrines—as extraneuronal metabolites—may provide good markers for release of catecholamines from a pheochromocytoma. Furthermore, substantial production of metanephrines within adrenal tissue (18) suggests that metanephrines may be produced within the tumor itself.

In humans, metanephrines are extensively sulfate-conjugated (18, 19). Assays of metanephrines in urine depend on measurements after deconjugation to free metanephrines (19) so that measurements represent the sum of free and conjugated metabolites (total metanephrines). In contrast, good sensitivity of the assay for plasma metanephrines (20) enables measurements of both free and total metanephrines.

We compared the sensitivity, specificity, and positive and negative predictive values of tests for plasma free and total metanephrines with those of tests for plasma catecholamines and urinary total metanephrines. Study participants included a relatively large sample of patients with pheochromocytoma, patients with essential hypertension or secondary hypertension from causes other than pheochromocytoma, and patients with either heart failure or angina pectoris in whom sympathetically mediated catecholamine release would be expected to be increased.

Methods

Patients

Fifty-two patients with a histologically proven pheochromocytoma were studied. Thirty patients were studied retrospectively, and 22 were studied before the final diagnosis was made. The pheochromocytoma was benign in 39 patients and malignant in 13. Sixty-seven healthy, normotensive persons and 51 patients with essential hypertension served as a reference group. Blood samples were obtained from 23 patients with secondary hypertension (12 patients with renal artery stenosis, 2 with kidney disease, 1 with Cushing disease, 1 with primary hyperaldosteronism, and 7 with cyclosporine-induced hypertension) and from 50 patients with either heart failure or angina pectoris. The age, sex, and specialty center where the patients were studied for each of the five groups are shown in Table 1. Except for the few patients who were being treated with phenoxybenzamine, no patients with pheochromocytoma had been receiving medication for at least 2 weeks at the time of blood sampling. No patients with essential hypertension had been receiving medication for at least 4 weeks at the time of blood sampling. No patients with heart failure and 15 patients with secondary hypertension, arterial blood was obtained through an indwelling arm arterial catheter. Blood samples were collected into precooled tubes containing heparin or EGTA and glucose one and were centrifuged within 30 minutes to separate the plasma, which was stored frozen until assayed. All plasma catecholamine and urinary metanephrine assays were done within 2 weeks of sample collection. Seven of the 52 pheochromocytoma samples were assayed for plasma metanephrines after being stored at −80°C for more than 2 years (range, 2 to 8 years), whereas the remaining 45 samples were assayed within 2 years of collection (22 samples within 4 weeks). In 46 of the 52 patients with pheochromocytoma, a 24-hour urine collection was obtained, with 30 mL of 6-M hydrochloric acid used as a preservative.

Blood and Urine Samples

All patients refrained from ingesting methylxanthine-containing food products and from smoking after midnight on the day before blood sampling. Blood was collected from an indwelling catheter in an antecubital vein after the patients had rested supine for 20 minutes. In 39 patients with heart failure and 15 patients with secondary hypertension, arterial blood was obtained through an indwelling arm arterial catheter. Blood samples were collected into precooled tubes containing heparin or EGTA and glucose one and were centrifuged within 30 minutes to separate the plasma, which was stored frozen until assayed. All plasma catecholamine and urinary metanephrine assays were done within 2 weeks of sample collection. Seven of the 52 pheochromocytoma samples were assayed for plasma metanephrines after being stored at −80°C for more than 2 years (range, 2 to 8 years), whereas the remaining 45 samples were assayed within 2 years of collection (22 samples within 4 weeks). In 46 of the 52 patients with pheochromocytoma, a 24-hour urine collection was obtained, with 30 mL of 6-M hydrochloric acid used as a preservative.

Analytic Methods

Plasma metanephrines were assayed at the National Institutes of Health (NIH) using liquid chromatography with electrochemical detection (20). Concentrations of total metanephrines (the sum of concentrations of free and sulfone conjugated metanephrines) were measured after incubation of 0.25 mL of plasma with 0.1 units of sulfatase (Sigma Chemical Company, St. Louis, Missouri) at 37°C for 30 minutes. The detection limits were 0.013 nmol/L for normetanephrine and 0.019 nmol/L for metanephrine. At a plasma normetanephrine concentration of 0.31 nmol/L and a metanephrine concentration of 0.21 nmol/L, the interassay coefficients of variation were 12.2% for normetanephrine and 11.2% for metanephrine. As previously reported (20), the presence of acetaminophen in samples of plasma can substantially interfere with measurements of plasma normetanephrine concentrations. Therefore, this analgesic must not be used by patients for several days before blood samples are collected. No analytic interference of various other drugs with this assay has been shown (20).

Plasma catecholamines were assayed using liquid chromatography. Electrochemical detection was used for quantification at the NIH (21), and fluorometric detection was used at St. Radboud University Hospital, Nijmegen, the Netherlands (22). At the NIH, the detection limits were 0.006 nmol/L for norepinephrine and 0.010 nmol/L for epinephrine. At a plasma norepinephrine concentration of 2.4 nmol/L and an epinephrine concentration of 0.39 nmol/L, the interassay coefficients of variation were 6.5% for norepinephrine and 11.4% for epinephrine. At St. Radboud University Hospital, the detection limits for norepinephrine and epinephrine were 0.002 nmol/L and 0.003 nmol/L, respectively. At plasma concentrations of 1.02 nmol/L for norepinephrine and 0.15 nmol/L for epinephrine, interassay coefficients of variation were 9.5% for norepinephrine and 7.2% for epinephrine.

Urinary concentrations of metanephrines were measured according to a previously described method (23); the upper reference limit of the normal range for the 24-hour urinary output of metanephrines was 6.8 μmol/d.

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Table 1. Patient Characteristics*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normotension</th>
<th>Essential Hypertension</th>
<th>Study Group</th>
<th>Heart Failure or Angina Pectoris</th>
<th>Pheochromocytoma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients, n</td>
<td>67</td>
<td>51</td>
<td>23</td>
<td>50</td>
<td>52</td>
</tr>
<tr>
<td>Mean age ± SD (range), y</td>
<td>39 ± 12 (20–72)</td>
<td>43 ± 13 (16–69)</td>
<td>48 ± 14 (20–69)</td>
<td>57 ± 11 (34–81)</td>
<td>39 ± 13 (11–71)</td>
</tr>
<tr>
<td>Male/female, n/n</td>
<td>40/27</td>
<td>24/27</td>
<td>14/9</td>
<td>42/8</td>
<td>28/24</td>
</tr>
<tr>
<td>Study center (NIH/SR/SH), n/n/n</td>
<td>36/31/0</td>
<td>1/50/0</td>
<td>17/15</td>
<td>13/7/30</td>
<td>41/11/0</td>
</tr>
</tbody>
</table>

* NIH = National Institutes of Health; SH = Sahlgrens Hospital; SR = St. Radboud University Hospital.
Data Analysis

Because plasma concentrations of catecholamines and metanephrines were not normally distributed, only medians and ranges are presented for these concentrations. Differences in plasma concentrations of metanephrines and catecholamines among patients with pheochromocytoma and other groups were tested using the Kruskal–Wallis test. We assessed relations among variables using the Spearman rank correlation coefficient.

Normal distributions of plasma concentrations of catecholamines and metanephrines were obtained after logarithmic transformation of the data. Thus, upper reference limits, defined as the 97.5th percentile, were determined after logarithmic transformation of individual values for the combined data from normotensive persons and those with essential hypertension (118 persons). The 97.5th percentiles were calculated from the antilogarithm of the mean plus 2 standard deviations of the transformed data. A false-negative result of a test for plasma metanephrines in a patient with pheochromocytoma was defined as plasma concentrations of both normetanephrines and metanephrines that were below their respective upper reference limits. Similarly, a false-negative result of a test for plasma catecholamines was defined as plasma concentrations of norepinephrine and epinephrine that were below their respective upper reference limits. A false-positive result of a test for plasma metanephrines in patients without pheochromocytoma was defined as a plasma concentration of either normetanephrine or metanephrine that was equal to or above the upper reference limits. Similarly, a false-positive result of a test for plasma catecholamines was defined as a plasma concentration of either norepinephrine or epinephrine that was equal to or greater than the upper reference limits. We calculated the sensitivity and specificity (with 95% CIs), pretest and post-test probabilities, and positive and negative predictive values for each analyte (24).

Differences in tumor-associated elevations in plasma catecholamine concentrations and free and total metanephrines concentrations were assessed from the fold-increases in plasma concentrations of compounds in patients with pheochromocytoma that were greater than median values in the normotension and essential hypertension reference group. We computed mean ± SE fold-increases after logarithmic transformation of individual fold-increases. We estimated differences among fold-increases by analysis of variance; post hoc tests were done with the Scheffe F-test.

Receiver-operating characteristic curves were constructed from the relation between the rates of true-positive and false-positive results (that is, sensitivity compared with 1 minus the specificity) for diagnosis of pheochromocytoma that are based on different upper reference limits for each analyte (25). These curves enabled us to compare the sensitivity and specificity of tests for plasma metanephrines for diagnosing pheochromocytoma with those of tests for plasma catecholamines, as a function of different upper reference limits for each analyte. The areas under the receiver-operating characteristic curves for plasma catecholamines and metanephrines were calculated as summary measures of the diagnostic power that were independent of upper reference limits. We calculated the difference between the two areas and tested them according to the method of Hanley and McNeil (26).

Results

Plasma Concentrations of Catecholamines and Free and Total Metanephrines

Plasma concentrations of free normetanephrine and metanephrine in the normotension and hypertension reference groups were not normally distributed until the data were logarithmically transformed (Figure 1). Ranges of plasma concentrations of normetanephrine and metanephrine were wider and the values were considerably higher ($P < 0.001$) in patients with pheochromocytoma than in any other patient group (Table 2).

In each group, plasma concentrations of total metanephrines were much higher than concentrations of free metanephrines; only a small proportion (<7%) of the normetanephrine or metanephrine in plasma was in the free form (Table 2). Like the free metanephrines, ranges of plasma concentrations of total metanephrines were much wider and the values much higher ($P < 0.001$) in patients with pheochromocytoma than in any other patient group. Similarly, ranges of plasma concentrations of norepinephrine and epinephrine were wider in patients with pheochromocytoma than in other groups, but only norepinephrine concentrations were consistently higher ($P < 0.001$) in patients with pheochromocytoma than in other groups.

Accuracy of Tests for Plasma Metanephrines

The upper reference limits were 0.66 nmol/L for plasma normetanephrine and 0.30 nmol/L for metanephrine. Only 1 of the 52 patients with pheochromocytoma had a plasma concentration of normetanephrine within the normal range (Figure 2, top), that is, a false-negative result.
However, this patient (patient 42, Table 3) also had an elevated plasma metanephrine concentration. Thus, when both metabolites were considered in the diagnosis rather than plasma normetanephrine alone, the number of false-negative results was reduced from 1 to 0, yielding a sensitivity and negative predictive value of 100% (Table 4). In 29 of the 191 patients (15%) without pheochromocytoma, a test for plasma normetanephrine or metanephrine yielded a false-positive result (Figure 2). Six of these 29 false-positive results were obtained in patients with renal artery stenosis or renal failure, and 16 were obtained in patients with heart failure.

Accuracy of Tests for Plasma Catecholamines

The upper reference limits were 3.00 nmol/L for norepinephrine and 0.54 nmol/L for epinephrine. In contrast to the one patient with pheochromocytoma and a false-negative result of the plasma normetanephrine test, 10 patients had false-negative plasma norepinephrine test results (Figure 2, top). Of these 10 patients, 2 had elevated plasma epinephrine concentrations (patients 32 and 34; Table 3); thus, the number of false-negative results was reduced from 10 to 8 when the diagnosis was based on plasma concentrations of both norepinephrine and epinephrine rather than on norepinephrine concentrations alone. This resulted in a sensitivity of 85% (Table 4). Tests of plasma catecholamines yielded false-positive results in 35 (18%) of the 191 patients without pheochromocytoma (Figure 2). In 19 of these 35 patients, results of tests for plasma metanephrines were also false-positive. Seven of these 35 false-positive results were obtained in patients with renal artery stenosis or renal failure, and 21 were obtained in patients with heart failure.

Accuracy of Tests for Urinary Metanephrines

Twenty-four-hour urine specimens were obtained from 46 of the 52 patients with pheochromocytoma and were not obtained from patients in any other group. The median urinary excretion rate of metanephrines in these patients was 24.2 μmol/d (range, 2.1 to 242 μmol/d). Use of an upper reference limit of 6.8 μmol/d for the urinary excretion of metanephrines in normotensive persons (23) yielded false-negative results in 5 of the 46 patients and a sensitivity of 89% (95% CI, 76% to 96%); all 5 patients had increased plasma concentrations of metanephrines, but only 3 had increased plasma concentrations of catecholamines. Creatinine excretion among the 5 patients with normal urinary excretion of metanephrine was within the normal range (1 to 2.5 g/d). Use of an upper reference limit of 9.5 μmol/d in hypertensive patients (4)
Table 3. Neurochemical Characteristics of 11 Patients with Pheochromocytoma and Normal (False-Negative) Plasma Concentrations of Norepinephrine or Normetanephrine

<table>
<thead>
<tr>
<th>Patient</th>
<th>Clinical Syndrome</th>
<th>Norepinephrine</th>
<th>Epinephrine</th>
<th>Normetanephrine</th>
<th>Metanephrine</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Sporadic</td>
<td>2.80</td>
<td>0.20</td>
<td>1.03†</td>
<td>0.28</td>
</tr>
<tr>
<td>21</td>
<td>Sporadic</td>
<td>2.90</td>
<td>0.36</td>
<td>3.39†</td>
<td>1.13†</td>
</tr>
<tr>
<td>27</td>
<td>Sporadic</td>
<td>0.69</td>
<td>0.53</td>
<td>1.98†</td>
<td>0.37†</td>
</tr>
<tr>
<td>32</td>
<td>Sporadic</td>
<td>2.93</td>
<td>0.93*</td>
<td>4.38†</td>
<td>2.31†</td>
</tr>
<tr>
<td>34</td>
<td>Sporadic</td>
<td>1.73</td>
<td>1.26*</td>
<td>17.19†</td>
<td>16.52†</td>
</tr>
<tr>
<td>38</td>
<td>Sporadic</td>
<td>2.42</td>
<td>0.17</td>
<td>9.44†</td>
<td>0.21</td>
</tr>
<tr>
<td>42</td>
<td>Cushing</td>
<td>4.21*</td>
<td>1.61*</td>
<td>0.48</td>
<td>0.55*</td>
</tr>
<tr>
<td>43</td>
<td>von Hippel-Lindau</td>
<td>2.08</td>
<td>0.03</td>
<td>1.69</td>
<td>0.06</td>
</tr>
<tr>
<td>48</td>
<td>Multiple endocrine neoplasia</td>
<td>1.83</td>
<td>0.21</td>
<td>4.10†</td>
<td>1.40*</td>
</tr>
<tr>
<td>49</td>
<td>Multiple endocrine neoplasia</td>
<td>1.74</td>
<td>0.32</td>
<td>1.28*</td>
<td>3.85*</td>
</tr>
<tr>
<td>50</td>
<td>von Hippel-Lindau</td>
<td>2.43</td>
<td>0.04</td>
<td>1.71*</td>
<td>0.18</td>
</tr>
<tr>
<td>Upper reference limit</td>
<td>3.00</td>
<td>0.54</td>
<td>0.66</td>
<td>0.30</td>
<td></td>
</tr>
</tbody>
</table>

* Denotes a concentration above the upper reference limits.
† Denotes a concentration more than threefold above the upper reference limits.

Table 4. Characteristics of Tests for Plasma Metanephrines and Catecholamines

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sensitivity (95% CI)</th>
<th>Specificity (95% CI)</th>
<th>Positive Predictive Value</th>
<th>Negative Predictive Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metanephrines*</td>
<td>100 (52/52) (94 to 100)</td>
<td>85 (162/191) (79 to 90)</td>
<td>64 (52/81)</td>
<td>100 (162/162)</td>
</tr>
<tr>
<td>Total metanephrines</td>
<td>98 (42/43) (68 to 100)</td>
<td>82 (112/137) (74 to 88)</td>
<td>63 (42/67)</td>
<td>99 (112/113)</td>
</tr>
<tr>
<td>Catecholamines</td>
<td>85 (44/52) (72 to 93)</td>
<td>82 (156/191) (75 to 87)</td>
<td>56 (44/79)</td>
<td>95 (156/164)</td>
</tr>
</tbody>
</table>

* "Metanephrines" refers to free normetanephrine and metanephrine. "Total metanephrines" refers to sulfobenzylated and free normetanephrine and metanephrine. The sensitivity of (total) metanephrines for diagnosis of pheochromocytoma was calculated from patients with both a false-negative plasma (total) metanephrine test result and a false-negative (total) metanephrine test result. The specificity of catecholamines was calculated from patients with both a false-negative plasma norepinephrine test result and a false-negative epinephrine test result. The specificity of catecholamines was calculated from patients with either a false-positive plasma (total) metanephrine test result or a false-positive (total) metanephrine test result. The specificity of catecholamines was calculated from patients with either a false-positive plasma norepinephrine test result or a false-positive epinephrine test result.

yielded 10 false-negative results and a sensitivity of 78% (CI, 64% to 89%).

Accuracy of Tests for Plasma Metanephrines Compared with Tests for Catecholamines

Tumor-associated elevations in plasma normetanephrine concentrations were 153% greater than those in plasma norepinephrine and 64% greater than those in plasma concentrations of total normetanephrine (Figure 3, top). Tumor-associated elevations in plasma metanephrine concentrations were 70% greater than those in epinephrine concentrations but did not differ from those in total metanephrine concentrations (Figure 3, bottom). Increases in plasma concentrations of total normetanephrine were 54% greater than increases in plasma concentrations of norepinephrine, whereas increases in total metanephrine concentrations were 46% greater than increases in epinephrine concentrations.

Among the 11 patients with pheochromocytoma and equivocal results of tests for normetanephrine or norepinephrine (Table 3), 17 positive results were obtained for tests for metanephrines (normetanephrine, 10 results; metanephrine, 7 results); only 4 positive results were obtained for tests for catecholamines (norepinephrine, 1 result; epinephrine, 3 results). In 7 of these 11 patients, plasma normetanephrine or metanephrine concentrations were elevated more than three times the upper reference limits for metanephrines; no patients had elevations in plasma norepinephrine or epinephrine concentrations greater than three times the respective upper reference limits.

Receiver-operating characteristic curves, which show the relation between rates of true-positive and false-positive results at different decision thresholds (that is, at different upper reference limits of plasma concentrations of metanephrines and catecholamines), confirmed the superiority of tests for plasma metanephrines over tests for plasma catecholamines for the diagnosis of pheochromocytoma, regardless of the reference limits used to define an abnormal test result (Figure 4, top). The area under the curve for plasma metanephrines (0.977 ± 0.015) was greater than that for plasma catecholamines (0.917 ± 0.027) (P = 0.03).

The relation between pretest and post-test probabilities—estimated from the sensitivity and specificity values listed in Table 4—show that as the prevalence rate (that is, the pretest probabilities) increases, the post-test probabilities similarly increase for diagnoses that are based on plasma concentrations of metanephrines and catecholamines (Figure 4, bottom). The negative predictive value of tests for plasma metanephrines for the diagnosis of pheochromocytoma remained constant at 100% for all prevalence rates, whereas the negative predictive value of...
tests for plasma catecholamines decreased with increasing prevalence rates.

In terms of positive and negative predictive values, measurement of plasma concentrations of total normetanephrine and metanephrine provided no advantage over measurement of free metanephrine concentrations (Table 4). However, measurements of plasma concentrations of total metanephrines provided greater sensitivity for the diagnosis of pheochromocytoma than measurements of plasma concentrations of catecholamines.

Discussion

Because a pheochromocytoma secretes catecholamines directly into the circulation, any of several means to detect the tumor by assays of plasma or urinary catecholamines and their metabolites should theoretically prove adequate. However, the occurrence of false-nega-
The negative predictive value of normal plasma concentrations of metanephrines was superior to that of normal plasma catecholamines regardless of prevalence rates (Figure 3, bottom), a disparity that increased with increasing prevalence. Even at the highest prevalence rates, normal plasma concentrations of metanephrines almost exclude diagnosis of pheochromocytoma. This means that in a general practice setting or in patients in whom pheochromocytoma is strongly suspected (for example, patients at a referral center who have hypertension, headache, and adrenal mass), normal plasma concentrations of metanephrines may exclude the diagnosis of pheochromocytoma.
concentrations. It is the free, not the conjugated, meta-

In conclusion, normal plasma concentrations of meta-

A limitation of our study is the lack of a reference
group of patients with a panic disorder syndrome; a di-
agnosis of pheochromocytoma in these patients must
sometimes be excluded (28). Stress-induced elevations
of plasma catecholamines in these patients may present a
diagnostic challenge. Because mild mental stress causes
little change in plasma concentrations of metanephrines
despite significant increases in plasma catecholamine
concentrations (18), measurements of plasma concentrations
of metanephrines may be particularly useful for excluding
pheochromocytoma in patients with a panic disorder.

Greater and more consistent tumor-associated increases
in plasma concentrations of metanephrines than in cate-
cholamine concentrations explain the better sensitivity of
the test for the former for diagnosing pheochromocytoma.

Thus, metabolism of catecholamines after they are re-
leased by a tumor into the circulation is not responsible for
the greater and more consistent increases in plasma
concentrations of metanephrines compared with those in
catecholamine concentrations in patients with a pheochro-
myctoma. The production of 90% of plasma metanephrine
and as much as 40% of plasma normetanephrine from metabolism of catecholamines within the adrenal
glands (18, 29) suggests that metanephrines are produced
within the tumor itself. This conclusion is supported by
observations of high tumor-tissue concentrations of meta-
ephrines (30, 31) and high plasma normetanephrine con-
centrations in the venous effluent of pheochromocytomas
(32). The conclusion is also supported by our findings
reported here and elsewhere (33) that tumor size is a
determinant of metabolite production but not of catechol-
amine release. Thus, even when pheochromocytomas are
quiescent and are not releasing catecholamines, they ap-
tear to be actively metabolizing catecholamines to meta-
nephrines.

Our results confirm the high sensitivity and specificity
of tests for plasma total metanephrines for the diagnosis
of pheochromocytoma that has been shown previously
(34); however, only concentrations of total metanephrines
were considered in that study. We found that measure-
ment of total (unconjugated and conjugated) metanephi-
rines had no advantage over measurement of free (un-
conjugated) metanephrines. Rather, the presence of a
tumor causes relatively larger increases in free normeta-
ephrine concentrations than in total normetanephrine
concentrations. It is the free, not the conjugated, meta-
ephrines that are produced within chromaffin tissue (un-
published observations). Thus, although plasma concen-
trations of total metanephrines are technically easier to
measure than plasma concentrations of free metanephi-
rines, the latter yield superior results.

Consistent with findings in previous studies (2, 11),
measurement of urinary metanephrines yielded false-neg-
ative results in a few patients. Why would a test for
urinary metanephrines be less sensitive than a test for
plasma concentrations of the same compounds? One ex-
planation is that a small percentage of patients in any
large-scale study would be expected to provide an incom-
plete urine collection; this would yield false-negative re-
results. However, the normal creatinine excretion in the
patients with false-negative results of tests for urinary
metanephrines rules out this explanation. Another possi-
ble explanation is that the assay technique used (23) is a
colorimetric method. An assay for urinary metanephrines
that uses the high-performance liquid chromatography
technique might be superior to the colorimetric tech-
nique. Finally, individual differences in the renal conver-
sion of metanephrines to methoxyhydroxyphenylglycol
and vanillylmandelic acid might be responsible for some of
the false-negative results.

Plasma catecholamines were assayed at two centers,
whereas plasma metanephrines were assayed at one cen-
ter. The involvement of different laboratories in our study
could have resulted in wider distributions and higher up-
per reference limits for plasma catecholamines than might
have been obtained had measurements been done in one
laboratory. This in turn could have resulted in more false-
negative results for plasma catecholamines determined in
two laboratories than would have occurred in one. How-
ever, separate analysis of the data for the two centers
indicated a 14.6% rate of false-negative results for cat-
cholamines assayed at St. Radboud University Hospital
compared with 18.2% for those assayed at NIH. In addi-
tion, the reference limits of 3.00 nmol/L for norepineph-
rine and 0.54 nmol/L for epinephrine obtained in our
study were substantially lower than those of other studies
(4, 6, 10). Because many of the patients with equivocal
catecholamine test results had plasma concentrations of
catecholamines well below the upper reference limits, a
substantial reduction in these limits would be required to
influence the results.

In conclusion, normal plasma concentrations of meta-
nephrines exclude a diagnosis of pheochromocytoma, and
normal plasma catecholamines or urinary metanephrines
do not. Tests for plasma metanephrines are more sensi-
tive than tests for plasma catecholamines or urinary meta-
nephrines for the diagnosis of pheochromocytoma.

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