Deficiency of Vitamin B₁₂-Binding Alpha Globulin in Two Brothers

By RALPH CARMEL AND VICTOR HERBERT

ENDOGENOUS VITAMIN B₁₂ circulates bound to an alpha-1 glycoprotein.¹² Added vitamin binds primarily to a globulin with beta mobility electrophoretically, which may serve mainly a temporary transport function.³⁴ This beta globulin readily gives up its vitamin B₁₂ to cells, while the alpha globulin seems to serve as a circulating storage depot.³⁵⁶

With the exception of some conditions involving longstanding neutropenia,⁷⁸ deficiency of B₁₂-binding proteins has been reported in only two instances. In one,⁹ various features suggested poor B₁₂ binding by serum, but subsequently, the serum B₁₂-binding capacity was found to be normal.¹⁰ The other report¹¹ was of transient deficiency of B₁₂-binding beta globulin in a subject with pernicious anemia.

The following is a study of persistent B₁₂-binding alpha globulin deficiency in two brothers, which, to our knowledge, is the first report of such a defect.

CASE REPORTS

P.B., a 47 year old Puerto Rican-Corsican male, had a subtotal gastrectomy for recurrent gastric ulcer in July 1963. In May 1966, his serum B₁₂ level was 0 by coated charcoal assay,¹² with a hemoglobin of 11.9 Gm. per cent, white cell count of 11,300/mm³ with normal differential count, and platelet count of 260,000/mm³. Lobe average was normal (3.12 lobes/neutrophil); there were no megaloblastic changes. He had no antibody to either parietal cells or intrinsic factor. Gastric analysis revealed intrinsic factor; his Schilling test was normal (9.2 per cent excretion of a 2 μg. dose in 48 hours). Upper GI x-ray studies showed a normal gastric stump; small bowel follow-through revealed rapid transit time and slight dilation of the small intestine but no other abnormalities. Serum
iron was 67 μg. per cent, total iron-binding capacity 335 μg. per cent. Radioactive iodine uptake was normal.

In 1958 he had undergone mitral commissurotomy for rheumatic mitral stenosis. During that year hemoglobin ranged between 11.7 and 15.5 Gm per cent, and white cells between 7,900 and 9,500/mm.³ with normal differential counts. Blood morphology was unremarkable except for some red cell hypochromia. In 1966, 0.8–1.2 Gm. quinidine orally daily was begun for atrial fibrillation, and maintained to the present. It has been the only medication other than B₁₂ taken regularly.

Family history was not known except that his mother died of carcinoma of the colon, and his father of "stroke."

Physical examination revealed only the cardiac findings of a diastolic blowing murmur along the left sternal border with an opening snap, and a low-pitched apical rumble, and patchy dark pigmentation about the left ankle.

He was discharged on monthly vitamin B₁₂ (100 μg.) injections. In 1968, the patient was reevaluated because of low B₁₂-binding capacity by coated charcoal assay¹³ in his serum during a routine screening study. (The B₁₂ and B₁₂-binding protein values are listed in Table 1.) Serum B₁₂ levels were low by microbiologic assay¹⁴ as well as by coated charcoal assay. Hemoglobin was 13.5 Gm. per cent, white cell count 9,500/mm.³ with a normal differential count, platelet count 190,000/mm.³ and reticulocyte count 1.5 per cent. Red cell and white cell morphology was normal. Leukocyte alkaline phosphatase was normal. Hemoglobin electrophoresis revealed 30.5 per cent S, 63.4 per cent A, 4.1 per cent A₅, and 2.0 per cent F hemoglobin. Urine analysis, serum folate, bilirubin, urea nitrogen, cholesterol, SCOT, LDH, sugar, uric acid and lysozyme* levels were normal. A Schilling test was normal once again (22.9 per cent excretion of a 2 μg. dose in 48 hours). Urinary excretion of methylmalonic acid ‡ was within normal limits. Small bowel x-ray study was now entirely normal, as were 72 hour fecal fat excretion, serum Vitamin A and carotene levels, and 5-hour d-xylose excretion. Glucose tolerance test showed a mildly diabetic pattern. X-ray of the skull was normal, as were serum corticosteroid, electrolyte, protein-bound iodine, and T₃ uptake levels.

Serum protein electrophoresis was unremarkable (4.38 Gm. per cent albumin, 0.31 Gm. per cent α₁ globulin, 0.75 Gm. per cent α₂ globulin, 0.88 Gm. per cent β globulin, and 1.19 Gm. per cent γ globulin), as were immunoglobulin determinations. Haptoglobin was 158 mg. per cent, serum iron 59 μg. per cent, total iron-binding capacity 432 μg. per cent, and ceruloplasmin 55.8 mg. per cent (normal: 20–40). Thyroid-binding globulin was 22.3 μg. per cent and pre-albumin 161 μg. per cent (normal: 17–25 and 180–300 respectively).§ Urinary amino acid excretion was quantitatively normal.

Vitamin B₁₂ therapy has been discontinued at present.

Summary

P. B., a 47 year old male, was found to have a low serum B₁₂ with low levels of B₁₂-binding capacity, primarily of the α₁ globulin component. No other protein abnormalities could be found. Other conditions present in the patient were rheumatic heart disease, postgastrectomy status, sickle cell trait, iron deficiency, and mild diabetes mellitus; the only drug taken regularly was quinidine. No evidence of any of the changes of B₁₂ deficiency could be found.

W.B., 46 year old brother of P.B., was discovered to have low serum B₁₂ by coated charcoal and microbiologic assays during survey of the family. The only positive historical and physical findings are those pertaining to his 10 year history of multiple sclerosis. He has not been taking any medications.

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† Assayed by Dr. A. Giorgio, New York Medical College, N. Y.
‡ Assayed by Drs. I. Sternlieb and I. H. Scheinberg, Albert Einstein College of Medicine, N. Y.
§ Assayed by Dr. J. H. Oppenheimer, Montefiore Hospital, N. Y.
VITAMIN B₁₂-BINDING ALPHA GLOBULIN

Laboratory data include 40.5 per cent hematocrit, white cell count of 10,500/mm³ with normal differential count, and platelet count of 240,000/mm³. No macro-ovalocytosis was seen. Although few 5-lobed and no 6-lobed neutrophil nuclei were seen, there was a mild increase in 4-lobed nuclei; lobe average was increased slightly at 3.45 lobes/neutrophil (normal: 3.17 ± 0.25). Serum folate was in the borderline-low range (4.5 ng/ml). Bone marrow examination showed no evidence of megaloblastic changes. In vitro study of deoxyuridine suppression of H³-thymidine incorporation into DNA by marrow cells was normal. Schilling test was normal (6.2 per cent excretion of a 2 µg. dose in an incomplete 24 hour urine collection). There was no circulating antibody to intrinsic factor. His B₁₂ and B₁₂-binding protein values are listed in Table 1. Hemoglobin electrophoresis was normal. Serum protein electrophoresis was normal. Serum haptoglobin, iron, iron-binding capacity, and quantitative urinary amino acid excretion were all within normal limits. Chromosomal analysis was unremarkable.*

Summary

The 46 year old brother of P. B. also had low serum B₁₂ with low B₁₂-binding alpha globulin. The only other condition present was multiple sclerosis, and he had been taking no medications. Although he had minimal white cell changes, no other evidence of B₁₂ deficiency, including the sensitive test of deoxyuridine suppression of H³-thymidine incorporation into DNA by bone marrow in vitro, could be found.

Family

Survey of all but one of the known blood relatives revealed normal B₁₂-binding capacity and serum B₁₂ levels in all members (Table 2). Other findings were unremarkable except for 3 members with sickle cell trait, one of whom had mild folate deficiency and anemia.

METHODS

Serum was either tested immediately or stored at −20 C. until used. All studies were performed in duplicate, and there was no significant difference between results of frozen and fresh samples. Saliva was obtained by expectoration, occasionally with the chewing of Parafilm®, and stored at −20 C. Gastric juice was aspirated, depepsinized, neutralized, and stored at −20 C. Leukocyte extracts were prepared by sedimentation in 3 per cent dextran, pH 6.8, with 0.2 per cent EDTA, pH 6.8, several washings with cold 0.1M phosphate buffer, pH 6.8, hypotonic shock lysis to remove red cells, sonication, and solution in acetate buffer (pH 5.5). After centrifugation at 20,000 g. for 10 minutes, the supernate was passed through a G-25 sephadex column. The extracts were stored at −20 C.

Serum B₁₂ was assayed by the coated charcoal method, as was the B₁₂-binding capacity of the various specimens. Fractionation of B₁₂-binding proteins was done by rapid DEAE-cellulose chromatography on a “baby” column. The beta globulin fraction was eluted with 0.06M phosphate buffer, pH 6.3, and the alpha with 1M NaCl. Horizontal starch gel electrophoresis of serum overnight at 2 volts/cm. was done in a discontinuous system described by Poulik. (The serum had previously been saturated with excess Co⁵⁷⁸B₁₂ of specific activity of 19.29 µc./µg., the unbound vitamin being removed with coated charcoal.) The gel was cut in 1 cm. strips which were counted in a well-type scintillation counter for 10,000 counts.

Intravenous B₁₂ disappearance study was performed by injecting 0.45 µg. sterile Co⁵⁷B₁₂ (19.29 µc./µg.) into a fore-arm vein, and obtaining venous blood samples from the other arm at various intervals. In addition, all stool and urine, and periodic saliva specimens, were collected for the first 72 hours.

Inhibitory effect of the subject’s serum on serum binding of vitamin B₁₂ was studied, using normal sera as simultaneous controls. Various volumes, up to 0.5 ml., of P.B. serum

*Performed by Dr. L. Hsu, The Mount Sinai Hospital, N. Y. Laboratory of Dr. K. Hirschhorn.
Table 1—B12 and B12-Binding Capacity of P.B. and W.B.

<table>
<thead>
<tr>
<th>Date</th>
<th>Bu</th>
<th>UB12 BC*</th>
<th>% UB12BCa</th>
<th>Total a+f</th>
</tr>
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<tbody>
<tr>
<td>P.B.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/23/66</td>
<td>0</td>
<td>904</td>
<td>21.8</td>
<td>197</td>
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<tr>
<td>10/23/67</td>
<td>62</td>
<td>874</td>
<td>18.7</td>
<td>225</td>
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<tr>
<td>3/18/68</td>
<td>34</td>
<td>750</td>
<td></td>
<td></td>
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<tr>
<td>3/22/68</td>
<td>31</td>
<td>968</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/28/68</td>
<td>74</td>
<td>1328</td>
<td>19.4</td>
<td>332</td>
</tr>
<tr>
<td>4/5/68</td>
<td>172</td>
<td>654</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/27/68</td>
<td>87</td>
<td>638</td>
<td>15.4</td>
<td>185</td>
</tr>
<tr>
<td>W.B.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/27/68</td>
<td>93</td>
<td>964</td>
<td>17.7</td>
<td>264</td>
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<tr>
<td>5/16/68</td>
<td>34</td>
<td>1014</td>
<td>11.6</td>
<td>152</td>
</tr>
</tbody>
</table>

Normal >150 pg./ml. 980-1756 pg./ml. 15-25% 347-1282 pg./ml.

* UB12BC = Unbound B12 binding capacity.
† Calculated by adding serum B12 value to unbound α B12BC (obtained by rapid chromatography).
§ 3 days after receiving 1000 μg B12 IM.
§ Other random UB12BC values: 768, 825, 805, 728.
" Total a: (Mean ± S.D.) = 235 ± 70; 19 normal subjects = 619 ± 215; the difference is highly significant (p < 0.005).

Table 2—Family Survey

<table>
<thead>
<tr>
<th>Age</th>
<th>Sex</th>
<th>B12</th>
<th>UB12BC*</th>
<th>% UB12BCa</th>
<th>Total a+f</th>
<th>Saliva UB12BC (pg./0.1 ml.)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Children of P.B.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.B.</td>
<td>23</td>
<td>F</td>
<td>451</td>
<td>1716</td>
<td>12.9%</td>
<td>672</td>
</tr>
<tr>
<td>P.B. Jr.</td>
<td>20</td>
<td>M</td>
<td>274</td>
<td>1333</td>
<td>19.1%</td>
<td>526</td>
</tr>
<tr>
<td>S.B.</td>
<td>9</td>
<td>F</td>
<td>443</td>
<td>1069</td>
<td>19.1%</td>
<td>647</td>
</tr>
<tr>
<td>Children of L.B.</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.B.</td>
<td>4</td>
<td>F</td>
<td>787</td>
<td>1844</td>
<td>18.6%</td>
<td>1130</td>
</tr>
<tr>
<td>D.B.</td>
<td>3</td>
<td>M</td>
<td>664</td>
<td>1296</td>
<td>21.9%</td>
<td>948</td>
</tr>
<tr>
<td>Brother of P.B. &amp; W.B.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H.B.</td>
<td>42</td>
<td>M</td>
<td>186</td>
<td>1360</td>
<td>19.7%</td>
<td>454</td>
</tr>
<tr>
<td>Children of H.B.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.B.</td>
<td>14</td>
<td>F</td>
<td>352</td>
<td>1484</td>
<td>18.0%</td>
<td>619</td>
</tr>
<tr>
<td>N.B.</td>
<td>11</td>
<td>M</td>
<td>569</td>
<td>1844</td>
<td>27.4%</td>
<td>1074</td>
</tr>
</tbody>
</table>

* UB12BC = Unbound B12 binding capacity.
† Calculated by adding serum B12 value to α UB12BC.

were presaturated with non-radioactive B12, the excess free B12 then being removed with hemoglobin-coated charcoal. These were then incubated with 0.1 ml. of various normal sera, or with high-alpha-binder content sera from patients with chronic myelogenous leukemia, for 30 minutes at room temperature. Two ng Co57B12 were added and, after 30 minutes' incubation, unbound Co57B12 was removed by coated charcoal. The amount bound was then compared to that bound by the sera without preincubation with test serum. The effect of leukocyte extract on serum binding was similarly tested.

RESULTS

Serum B12-binding Protein

Serum B12-binding capacity was low in 10 of 11 determinations of subject P.B. and in both determinations of W.B. (Table 1). This decrease was most prominent in the alpha globulin component, as determined by rapid DEAE-
VITAMIN B₁₂-BINDING ALPHA GLOBULIN

Total B₁₂-binding capacity
Unbound B₁₂-binding capacity
Total B₂ binding alpha globulin

Fig. 1.—Serum B₁₂-binding capacity of P.B. and W.B., and of various control groups (number in parentheses indicates number of subjects). Bars represent mean and range. The lowest value in the untreated pernicious anemia group is a patient with transient B₁₂-binding beta globulin deficiency, discussed below.

cellulose chromatography (Fig. 1) and starch gel electrophoresis (Fig. 2). There was also decrease in beta globulin binding, P.B. demonstrating a mean of 757 pg./ml. beta globulin B₁₂-binding capacity for 4 separate determinations and W.B. 845 pg./ml. for 2 determinations, compared to 1058 pg./ml. for the 19 normal subjects tested. (The difference between the values of P.B. and normals is significant, p being < 0.01).

Leukocyte B₁₂-binding Protein

Leukocyte extracts of both subjects manifested virtually absent B₁₂ binding (P.B. 24 pg./10⁷ leukocytes and W.B. 43 pg./10⁷ leukocytes). This is in contrast to various control subjects in our laboratory (Fig. 3) and others’ published data.¹⁹,²⁰ The only condition in which nearly as low levels were seen was chronic lymphocytic leukemia with marked preponderance of lymphocytes, which are poor in B₁₂-binding proteins.¹⁹,²¹,²² Both P.B. and W.B., however, had normal numbers of neutrophils and lymphocytes.

Furthermore, the minute amounts of binding protein present eluted with the beta globulin fraction on DEAE-cellulose chromatography, unlike the usual elution with alpha globulin of leukocyte B₁₂-binding proteins.

Saliva and Gastric Juice B₁₂-binding Protein

Saliva of the 2 subjects also demonstrated virtual absence of B₁₂-binding protein as compared to various controls, including the rest of the family (Fig. 4). Specimens from P.B., collected at various times between 1966 and 1968, had levels between 9 and 36 pg./0.1 ml.; W.B. saliva showed a binding capacity of 25 pg./0.1 ml.

The total B₁₂-binding capacity of P.B. gastric juice was low as well (102 pg./0.1 ml. in the residual, 156 pg./0.1 ml. in the basal, and 202 pg./0.1 ml. in the histamine-stimulated specimens); approximately half of this binding was shown to be due to intrinsic factor, which elutes with the beta globulins on DEAE-cellulose chromatography.¹⁷ Such low B₁₂-binding values are rarely seen in subjects with intrinsic factor, but occasionally in patients with pernicious anemia. Thus, of 100 consecutive gastric juice specimens containing intrinsic factor, only 5 bound less than 1000 pg./0.1 ml., whereas of 100 con-
Fig. 2.—Starch gel electrophoresis and localization of Co$^{57}$B$_{12}$ radioactivity of P.B. serum compared to normal (below) and chronic myelogenous leukemia (above) sera. (Gel is stained with Amido Schwartz.) 1-Albumin; 2-probably transferrin, to left of which lies the majority of the alpha-1 binder of Co$^{57}$B$_{12}$; and to the right the beta globulin; 3-origin. Total radioactivity of P.B. serum recovered in the starch gel was half that of the normal serum. (CPM = counts/minute.)

In consecutive specimens lacking intrinsic factor, 28 had such levels (unpublished data from our laboratory).

**Intravenous Co$^{57}$B$_{12}$ Disappearance Study**

P.B. was given 0.45 μg. Co$^{57}$B$_{12}$, a less than saturating dose, intravenously (Fig. 5). The early, rapid phase of disappearance probably reflects the transient binding by beta globulin, whereas the later, slow phase reflects the tight binding by alpha globulin.$^3$ In P.B. the early phase was comparable to that seen in normal subjects. The later phase may have been at a slightly lower plateau than is seen usually in normal subjects, and was much lower than is seen in B$_{12}$ deficient states.$^{23-26}$ (His serum B$_{12}$ level on the day of the test, 4/27/68, was 87 pg./ml.) Over the first 3 days of the study, only 2.1 per cent of the injected dose appeared in the urine and 1.2 per cent in stool; none appeared in saliva.

**Effect of P.B. Serum on B$_{12}$ Binding by Other Sera**

Incubation of as much as 0.5 ml. P.B. serum with 0.1 ml. of various normal or high-alpha-binder content sera resulted in no significant decrease of B$_{12}$-binding capacity. Similarly, P.B. leukocyte extracts had no effect on B$_{12}$ binding by the various sera.
Fig. 3.—$B_{12}$-binding capacity of leukocyte extracts of P.B. and W.B., and of various control groups (number in parentheses indicates number of subjects). Bars represent mean and range. A = normals; B = chronic myelogenous leukemia; C = leukemoid reaction; D = polycythemia vera; E = secondary polycythemia; F = myeloid metaplasia; G = chronic lymphocytic leukemia.

Fig. 4.—$B_{12}$-binding capacity of saliva of P.B. and W.B., and of various control subjects. 1 = normals, 2 = pernicious anemia; 3 = chronic myelogenous leukemia; 4 = subjects' family; 5 = chronic leukopenia with low serum $B_{12}$-binding capacity.

Urinary $B_{12}$-binding Protein Excretion

Urine at no time contained measurable $B_{12}$-binding capacity, indicating no loss of the proteins by that route.

Discussion

The alpha-l globulin, a molecule with an approximate molecular weight of 120,000,27,28 carries endogenous vitamin $B_{12}$. It binds the vitamin tightly, and transfers $B_{12}$ poorly to cells in vitro.3,5,6 It appears to be closely similar to the $B_{12}$-binding protein found in saliva and neutrophils.20,28

When excess vitamin $B_{12}$ is added, the majority binds to a beta globulin,3,4,17 only 15-25 per cent binds to alpha globulin.13 This beta globulin, approximately 1/3 the size of the alpha,5,27 appears to be primarily a transport protein. It gives up $B_{12}$ fairly readily to cells in vitro.3,6,8 A postulated
Fig. 5.—Co$^{57}$B$_{12}$ disappearance from serum of P.B. Given 0.45 $\mu$g. Co$^{57}$B$_{12}$ intravenously at zero time. Subject’s weight = 54.5 Kg.; estimated plasma volume = 2470 ml. Data may be compared to Figure 7 of the report of Brody et al.,$^{24}$ where identical studies on normal and B$_{12}$-deficient subjects done in the same laboratory, are presented.

The schema is that, as vitamin B$_{12}$ enters the blood stream, it is bound primarily by beta globulin and delivered rapidly to cellular sites, and thence transferred to alpha globulin, some of which is intracellular or cell-bound and some freely circulating.$^5$ The alpha globulin may be an altered form of the beta or they may be two distinct proteins.

Elevated levels of these B$_{12}$-binding proteins occur in various conditions. Most of these are associated with a proliferative increase of neutrophils, the most striking example being chronic myelogenous leukemia.$^2, 7, 21, 29, 30$ Low levels are rare, having been observed in long-standing neutropenia.$^7, 8$ The exact relationship between B$_{12}$-binding protein levels and these diseases is not established.

Lawrence$^{11}$ reported a patient with pernicious anemia who exhibited deficiency of the beta globulin binder, which normalized after parenteral vitamin B$_{12}$ therapy. We have observed this phenomenon in a 66 year old man with pernicious anemia, who presented with a serum unsaturated B$_{12}$-binding capacity of 746 pg./ml., of which only 61 per cent was due to beta globulin (normal: 75-85 per cent). After monthly injections of 100 $\mu$g. B$_{12}$ for 18 months, unsaturated B$_{12}$-binding capacity was 1876 pg./ml., of which 79 per cent was now due to beta globulin. Our patient with pernicious anemia initially did not have an abnormal Schilling test when given exogenous intrinsic factor, suggesting that the transient B$_{12}$ malabsorption in Lawrence’s patient was the intestinal defect of B$_{12}$ absorption seen not infrequently in untreated pernicious anemia$^{31}$ and unrelated to the serum binding abnormality.

Horrigan and Heinle$^6$ reported a patient with possible defective in vivo binding of B$_{12}$, who required frequent injections of the vitamin or intravenous administration of normal plasma to maintain remission of her megaloblastosis. Intramuscular administration of 0.5 $\mu$g. Co$^{60}$B$_{12}$ resulted in excessive urinary excretion (60 per cent of the dose in 24 hours). Subsequently, she became increasingly refractory to therapy.$^{32}$ The nature of the B$_{12}$-binding problem was never established, since the B$_{12}$-binding capacity of her serum proved to be normal.$^{10}$

The two brothers reported here have persistent decrease in serum B$_{12}$-binding alpha globulin in the absence of chronic neutropenia. This was unresponsive
to vitamin B₁₂ therapy. The beta globulin binder for B₁₂ was slightly decreased as well, but transferrin, ceruloplasmin, haptoglobin, and thyroxine-binding protein were not reduced. The primary manifestation in both cases was a low serum B₁₂ level by coated charcoal assay. This low B₁₂ value was not a technical artifact, being also demonstrable on microbiologic assay. The serum unsaturated and total B₁₂-binding alpha globulin levels in the 2 subjects were lower than in normals or in subjects with pernicious anemia or B₁₂ deficiency due to other causes. Low values for total B₁₂-binding alpha globulin were sometimes noted in untreated pernicious anemia, but this appears to be primarily associated with the low B₁₂ levels, since the unsaturated alpha globulin binder values were not low. Thus, in patients with pernicious anemia in therapeutic remission, total alpha globulin levels were normal (Fig. 1). In contrast to this, there was no change in the levels of subject P.B. over 2 years, despite monthly injections of 100 µg B₁₂. Both B₁₂-binding alpha globulin and serum B₁₂ levels remained low. (One value was in the low normal range, but 10 others, earlier and later, were low.)

P.B. manifested no evidence of metabolic deficiency of vitamin B₁₂. Determination of methylmalonic acid excretion in the urine was, unfortunately, not done until after B₁₂ therapy was begun. It was normal despite the persistently low serum B₁₂ levels. W.B. also showed no abnormality save minimal white cell changes, which are the earliest morphologic changes of B₁₂ deficiency;32 his bone marrow was morphologically normal. Deoxyuridine suppression of H³-thymidine incorporation by his marrow in vitro, a sensitive measure of B₁₂ or folate deficiency,15 was normal and was unaffected by adding B₁₂ into the system, even when normal serum was added. It may be that in the case of W.B. the binding defect was just enough to produce only the very mildest manifestation of vitamin deficiency, although unrelated factors may have accounted for even this change.

The rapid disappearance from the blood stream of P.B. of Co⁵⁷B₁₂ given intravenously suggests that tissues were still able to store the vitamin adequately, as no significant amount was lost by excretion; this may account for the absence of metabolic evidence of B₁₂ deficiency. However, it is possible that maldistribution of the vitamin may have occurred.

In addition to deficiency of the protein in the serum, virtual absence of it in leukocyte extracts and saliva was noted. Since in the normal individual most, if not all, B₁₂-binding protein in these substances is alpha globulin,2⁰ its absence is easily demonstrable. This is not always the case with serum, where a large B₁₂-binding beta globulin fraction may obscure absence of the alpha globulin component due to technical problems. The absence in saliva, a fluid which normally has very high B₁₂-binding capacity,2⁰ has not been observed in any condition by us. Subject P.B. also had low B₁₂-binding capacity in his gastric juice, although this could be a reflection of changes due to gastrectomy.

The absence of B₁₂ binding by the subjects’ leukocyte extracts is unique. The only condition in which values approaching this are found is chronic lymphocytic leukemia, where the cause appears related to deficiency of neutrophils, which bind much B₁₂ normally (lymphocytes bind little B₁₂).1⁹,2¹,2² Both subjects had normal white cell counts with normal numbers of neutro-
phils. With the exception of the minimal hypersegmentation of neutrophil nuclei of W.B., the cells appeared normal microscopically.

The source of the $B_{12}$-binding alpha globulin in serum is unknown. Due to its high concentration in neutrophils, the high serum values seen in chronic myelogenous leukemia and various myeloproliferative disorders, and the low values seen in some neutropenias of long duration, it has been postulated that neutrophils are a major source.\(^7\,^{20}\,^{28}\) However, the electrophoretic mobility of leukocyte alpha globulin $B_{12}$-binder differs slightly from the alpha-1 globulin in serum. A distinct possibility exists that sialic acid content accounts for this difference,\(^28\) and that the two are otherwise identical. Indeed, the possibility also exists that the beta globulin binder is a monomer, or other variant, of the alpha globulin binder, and that cells, possibly including neutrophils, act primarily in converting one form to the other.\(^5\) Thus, it is worth noting that although the change in $B_{12}$-binding alpha globulin is the striking one in the disorders listed above and in our 2 subjects, beta globulin changes in the same direction, although of smaller magnitude, occur.\(^33\)

The cause of the binder deficiency, probably inherited, in the 2 subjects is hard to define. It may be that only circulating protein was absent, tissue binding by cells other than leukocytes being intact. Protein production may have been decreased, or a defective protein produced. Alternatively, release of the protein into leukocytes and the circulation may have been defective. There did not appear to be destruction or inhibition of $B_{12}$-binding capacity, as these could not be demonstrated in vitro, and no urinary excretory loss was found.\(^34\)

**SUMMARY**

Persistent deficiency of serum $B_{12}$-binding alpha-1 globulin was demonstrated in two brothers, manifesting primarily as low serum $B_{12}$ levels. Despite the inability of one subject to maintain normal levels of $B_{12}$ in the blood, as shown by persistently low serum values despite monthly injections of $B_{12}$, no evidence of metabolic $B_{12}$ deficiency could be found. Tissue $B_{12}$-storing ability appeared to be intact. His brother exhibited only minimal hypersegmentation of neutrophil nuclei; otherwise, he too presented a completely normal picture.

The normally present alpha globulin $B_{12}$-binder was virtually absent from saliva and peripheral leukocyte extracts of both subjects.

Current indirect evidence favors neutrophils as at least a partial source of the serum globulin.\(^33\) The cause of the possibly hereditary defect in the 2 subjects is unknown. Neither excessive $B_{12}$-binding protein excretion\(^34\) nor a destructive factor in their serum or leukocytes was found.

**SUMMARIO IN INTERLINGUA**

Un persistente carentia de seral globulina $\alpha$-1 a ligation de vitamina $B_{12}$ esseva demonstrate in duo fratres in qui le manifestation primari de ille abberration esseva basse nivellos seral de vitamina $B_{12}$. In despecto del incapacitate de un del subjectos de mantener normal nivellos de vitamina $B_{12}$ in le sanguine — un facto rendite evidente per le persistentemente basse valores seral malgrado injectiones mensual de vitamina $B_{12}$ — nulle prova de carentia metabolic de vitamina $B_{12}$ poteva esser establete. Le capacitate tissular pro thesaurizar vitamina $B_{12}$ pareva esser intacte. Le fratre de iste subjecto exhibiva solo minime grados de
VITAMIN B12-BINDING ALPHA GLOBULIN

hypersegmentation in su nucleo de neutrophilo. Alteremente etiam ill presentava un totalmente normal tableau.

Le normalmente presente globulina a ligator de vitamina B12 esseva virtualmente absente ab le saliva e ab extractos de leucocytos peripheric in ambele subjectos.

A base del currentemente disponibile evidentia indirecte ii pote esser stipulate que le neutrophilos es le font del globulina seral. Le causa del defecto, possibilemente hereditari, in le duo subjectos hic presentate non es cognoscite. Esseva trovate nulle excessive excretion de proteina a ligation de vitamin B12 e nufle factor destructive in le sero o in le leucocytos del probandos.

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