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# Vitamin B<sub>12</sub> Status after Right Hemicolectomy in Bowel Cancer Patients: A Feasibility Study

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## Abstract

**Introduction:** Terminal ileum resection in patients with Crohn's disease results in vitamin B<sub>12</sub> deficiency and these patients are routinely given B<sub>12</sub> supplementation to prevent anemia and neuropsychiatric disease. The effect of right hemicolectomy on B<sub>12</sub> status in cancer patients has not previously been studied. Total serum B<sub>12</sub> is an unreliable test. Second-line diagnostic tests measure methylmalonic acid (MMA) and homocysteine (tHcy) are also used. An assay measuring an active form of B<sub>12</sub> is available for routine use. This observational study investigated whether B<sub>12</sub> deficiency exists in patients after a right hemicolectomy for cancer.

**Methods:** Patients (n=28; age range=52-88 years) who had undergone a right hemicolectomy for cancer and been in remission for two years were identified from a database and recruited to an outpatient clinic along with an age-matched control group (n=27; age range=52-89 years). Vitamin B<sub>12</sub> status in both patients and controls was assessed by the measurement of vitamin B<sub>12</sub> (total and active), MMA and tHcy.

**Results:** Concentration of tHcy was significantly higher (p<0.05) in the surgical group (14.0 µmol/L) compared with the controls (11.1 µmol/L). There were no significant differences in total and active B<sub>12</sub>, folate and MMA concentrations between the two groups (p>0.05).

**Discussion:** Right hemicolectomy for malignancy is associated with an increase in tHcy concentrations although a larger study is required to determine the B<sub>12</sub> status in post-operative right hemicolectomy patients.

**Keywords:** Right hemicolectomy; Vitamin B<sub>12</sub> deficiency; MMA; tHcy; Cancer; Crohn's disease

## Introduction

Cancer Research UK reports bowel cancer as the fourth most common cancer for both men and women in the UK, with 41,112 bowel cancer cases in the UK, and 2,272 in Wales in 2013 [1]. Sixty- three per cent of bowel cancer patients had surgical intervention in 2015 [2] with some undergoing a right hemicolectomy with various degrees of the terminal ileum being resected.

There has been no study to investigate vitamin B<sub>12</sub> deficiency in people undergoing right hemicolectomy for malignancy however those who have had the same procedure for Crohn's disease are prescribed B<sub>12</sub> supplementation because of recognised deficiencies. Crohn's ileal resections of less than 20 cm in length have variable consequences on B<sub>12</sub> status [3] although patients who have had more than 20 cm of terminal ileum excised almost invariably have vitamin B<sub>12</sub> deficiency [4].

Vitamin B<sub>12</sub> plays a key role in DNA and cell metabolism and long term deficiency can cause severe and irreversible damage. Effects of B<sub>12</sub> deficiency include fatigue, bone marrow suppression, neurological features including stroke, and risk of cardiomyopathy [5-8]. It has been recognised that B<sub>12</sub> deficiency can cause symptoms of psychosis, mania, memory impairment, fatigue, irritation and personality changes. Deficiency can be treated with vitamin B<sub>12</sub> supplementation, which if given for life has the potential to improve well-being and longevity.

Vitamin B<sub>12</sub> (cobalamin) is bound to two proteins; transcobalamin (TC) and haptocorrin (HC). The transcobalamin-vitamin B<sub>12</sub> complex, also known as holotranscobalamin (HoloTC), contains the biologically available B<sub>12</sub> HoloTC mediates the uptake of B<sub>12</sub> by all cells utilising specific receptors whereas 80% of B<sub>12</sub> which is bound to HC is metabolically inert [8,9]. Measurement of total B<sub>12</sub> (cobalamin) in serum by immunoassay is the most widely available test for assessing B<sub>12</sub> status. However, this test

measures both the active and inactive forms and has a low sensitivity. Currently methylmalonic acid (MMA) and homocysteine (tHcy) are recommended as second line tests if total B<sub>12</sub> results are in the indeterminate range, as they are considered to be more sensitive tests although tHcy is less specific. Both MMA and tHcy depend on B<sub>12</sub> as a cofactor for their metabolism. An increase in MMA or total tHcy in folate replete individuals indicates B<sub>12</sub> deficiency in tissue [7,10]. The metabolically active B<sub>12</sub> can now be measured by an immunoassay and recent evidence suggests that this is a more reliable marker of impaired vitamin B<sub>12</sub> status than total B<sub>12</sub> [7,10]. However, it also recommended that MMA is used as a confirmatory test if the result is in the indeterminate range.

In this present study, we measure both total and active B<sub>12</sub>, tHcy and MMA in addition to other variables to determine B<sub>12</sub> status in patients who have undergone right hemicolectomies for cancer and in age-matched controls (controls).

## Materials and Methods

### Recruitment of participants

Adults treated with a right hemicolectomy for gastrointestinal cancer at Nevill Hall Hospital who had been in remission for two years or more were identified from an internal database and invited to join the study. Potential participants were excluded with the following conditions: already receiving vitamin B<sub>12</sub> supplementation, pregnant, anemic or unable to give written consent. The study gained ethical approval from the NHS South Central Hampshire B Research ethics committee (REC No 15/SC/0756 PR). All participants gave written informed consent. Twenty-eight participants attended a clinic where blood samples were taken along with twenty-seven age-matched controls (**Table 1**).

**Table 1** Descriptive characteristics for all participants (n=55) and for controls (n=27) and patient (n=28) subgroups.

	Total cohort	Controls	Patients	P
n (%)	55 (100%)	27 (49%)	28 (51%)	
Age (years)	75 (52-89)	77 (52-89)	74 (52-88)	0.933
Gender (M:F)	40:15	22:5	18:10	-
Total B <sub>12</sub> (ng/L)	317 (125-895) <sup>d</sup>	324 (195-895) <sup>b</sup>	295 (125-652) <sup>b</sup>	0.243
Active B <sub>12</sub> (pmol/L)	65.3 (23.4-257.0) <sup>a</sup>	69.3 (23.4-257.0)	63.7 (27.5-170.1) <sup>a</sup>	0.782
Folate (µg/L)	5.8 (1.5-20.0) <sup>d</sup>	5.8 (1.5-20.0) <sup>b</sup>	5.7 (2.3-16.0) <sup>b</sup>	0.902
MMA (µmol/L)	0.29 (0.16-2.80)	0.28 (0.21-0.81)	0.33 (0.16-2.80)	0.619
Homocysteine (µmol/L)	12.6 (6.5-38.0)	11.1 (6.9-34.5)	14 (6.5-38.0)	0.037
Haemoglobin (g/L)	136 ± 19 <sup>a</sup>	133 ± (24) <sup>a</sup>	139 ± (15)	0.256
MCV (fL)	89.0 (79-112) <sup>a</sup>	89 (80-112) <sup>a</sup>	90 (79-104)	0.549
Creatinine (µmol/L)	82 (59-148) <sup>c</sup>	77 (61-119) <sup>b</sup>	84 (59-148) <sup>a</sup>	0.223
eGFR (mL/min/1.73 m <sup>2</sup> ) (mean ± SD)	73 ± 17 <sup>c</sup>	78 ± 15 <sup>b</sup>	68 ± 17 <sup>a</sup>	0.040
TI Excised (cms)	-	-	80 (60-400)	-
Days post resection			1747 (770-2812) <sup>a</sup>	

Note: continuous variables are expressed as median (range) unless stated otherwise. tHcy, homocysteine; MMA, methylmalonic acid; eGFR, estimated glomerular filtration rate; MCV, mean cell volume. Missing number of samples are shown, a: n-1, b: n- 2, c: n-3, and d: n-4.

### Laboratory analyses

Blood samples were collected, transported to the laboratory within 30 minutes and analysed on the same day with the exception of plasma tHcy, plasma MMA, and active vitamin B<sub>12</sub>, where samples were stored at -80°C for up to one month prior to analysis. For plasma tHcy, samples were separated and frozen within 30 minutes of venepuncture.

Serum total B<sub>12</sub>, folate, creatinine and tHcy, were analysed on the Abbott ARCHITECT ci8200 analyser (Abbott Diagnostics, Berkshire, UK). Full blood count parameters including haemoglobin and mean cell volume (MCV) were performed by a SYSMEX XE-2100 analyser (SYSMEX, Kobe, Japan). Plasma

concentrations of MMA were determined by GC-MS. Serum active B<sub>12</sub> was analysed by an Abbott chemiluminescent microparticle immunoassay (CMIA) on the Abbott ARCHITECT ci8200 analyser. Within-batch coefficients of variation (CVs) were 4.1% and 5.3% at concentrations of 15.8 pmol/L and 46.8 pmol/L, respectively. Between-batch CVs were 7.6% and 5.7% at concentrations of 15.8 pmol/L and 46.8 pmol/L, respectively. Glomerular filtration rate was estimated using a four-variable MDRD equation. For the purpose of this study, renal disease was defined as estimated GFR (eGFR) <60 mL/min/1.73 m<sup>2</sup> [11]. Local reference ranges were used for all analytes with the exception of the reference range for active B<sub>12</sub> [12].

## Statistical Analysis

Data were analysed using statistical software (Analyse-It, Leeds UK and Sigmaplot V13 Systat Ltd, UK). Most of the data were not normally distributed and were expressed as median (range) unless stated otherwise. Non-parametric Mann-Whitney U-test was used for comparison between patients and controls. For normally distributed data the unpaired T-test was used. Spearman rank analysis was used to test for univariate relationships between markers of vitamin B<sub>12</sub> status with clinical variables. A *p* value of <0.05 was considered statistically significant. Agreement between different markers of B<sub>12</sub> status was undertaken using the weighted kappa test for agreement: kappa statistic ( $\kappa$ ) <0.2 was considered a poor strength of agreement.

## Results

Eleven of 26 (42%) patients and 10 of 26 (38%) controls had total B<sub>12</sub> concentrations within the indeterminate range (180-300 ng/L) (**Table 1**). In comparison, a slightly higher proportion of patients (56% (15 of 27)) and controls (48% (13 of 27)) had active B<sub>12</sub> concentrations in the indeterminate range (25-70 pmol/L). However, 3 of 26 (12%) patients demonstrated total B<sub>12</sub> deficiency (<180 ng/L) compared with none in the control group. Conversely, active B<sub>12</sub> results revealed that 1 of 27 controls (4%) was deficient (<25 pmol/L) compared with none in the patient group. Taken together, there was a high proportion of patients who were not replete in B<sub>12</sub>; 56% and 53% for active B<sub>12</sub> total B<sub>12</sub>, respectively. A slightly lower proportion of controls were not replete in B<sub>12</sub>; 50% for active B<sub>12</sub> and 40% for total B<sub>12</sub>.

Of those study participants (patients and controls) who were not replete in active B<sub>12</sub> (<70 pmol/L), only 9 of 30 (30%) and 8 of 30 (27%) had raised MMA (>0.42  $\mu$ mol/L) and tHcy (>16.0  $\mu$ mol/L) concentrations, respectively. Study participants who were not replete in total B<sub>12</sub> (<300 ng/L), 4 of 24 (17%) and 5 of 24 (21%) had raised MMA (>0.42  $\mu$ mol/L) and tHcy

(>16.0  $\mu$ mol/L) concentrations, respectively. Thus, agreement between total B<sub>12</sub> and MMA ( $\kappa$ =0.02), active B<sub>12</sub> and MMA ( $\kappa$ =0.07), tHcy and total B<sub>12</sub> and tHcy ( $\kappa$ =0.01), active B<sub>12</sub> and tHcy ( $\kappa$  = 0.02) for the diagnosis of B<sub>12</sub> deficiency was poor in this population. Of those with deficient total B<sub>12</sub> results (<180 ng/L; *n*=3 patients), active B<sub>12</sub> results were all in the indeterminate range or above, one MMA and two tHcy results were elevated, and one tHcy result was at the upper end of the reference range. In contrast, only one control had a deficient active B<sub>12</sub> result (<25 pmol/L). However total B<sub>12</sub> was in the indeterminate range and MMA and tHcy concentrations were both normal.

Plasma homocysteine concentration (14.0  $\mu$ mol/L) was significantly higher in patients compared with controls (11.1  $\mu$ mol/L) (*p*=0.037). Ten of 28 (36%) patients exhibited an elevated tHcy concentration (>16.0  $\mu$ mol/L) compared with 4 of 27 (15%) of controls. eGFR was significantly lower in patients (68 mL/min/1.73 m<sup>2</sup>) compared with controls (78 mL/min/1.73 m<sup>2</sup>) (*p*=0.04). However, only seven of the patients and four of the controls had eGFR <60 mL/min/1.73 m<sup>2</sup>. There were no significant differences (*p*>0.05) in total or active B<sub>12</sub>, MMA, haemoglobin (Hb) and mean cell volume (MCV) between the two groups. The prevalence for abnormal MMA (>0.42  $\mu$ mol/L) in patients and controls was 21% (6 of 28) and 19% (5 of 27), respectively.

Univariate analyses for the patient subgroup (**Table 2**) revealed that tHcy correlated negatively with folate and eGFR and positively with MMA. However, in the controls, tHcy only correlated negatively with folate (**Table 3**). In patients, total B<sub>12</sub> only correlated positively with active B<sub>12</sub> compared with total B<sub>12</sub> in control participants which correlated positively with active B<sub>12</sub>, folate and MCV. In patients, active B<sub>12</sub> correlated positively with total B<sub>12</sub> and negatively with MMA, and Hb. In the controls active B<sub>12</sub> correlated negatively with folate and positively with total B<sub>12</sub>. Due to the small study numbers, the independent effect of variables on B<sub>12</sub> status was not analyzed.

**Table 2** Correlation between vitamin B<sub>12</sub> status markers and clinical variables in patients (*n*=28).

	tHcy		Total B <sub>12</sub>		Active B <sub>12</sub>		MMA	
	<i>r<sub>s</sub></i>	<i>p</i>	<i>r<sub>s</sub></i>	<i>P</i>	<i>r<sub>s</sub></i>	<i>P</i>	<i>r<sub>s</sub></i>	<i>P</i>
tHcy	-	-	-0.27	0.19	-0.25	0.20	0.43	0.022
Total B <sub>12</sub>	-0.27	0.19	-	-	0.49	0.01	-0.16	0.42
Active B <sub>12</sub>	-0.25	0.20	0.49	0.01	-	-	-0.55	0.003
MMA	0.43	0.02	-0.16	0.42	-0.55	0.003	-	-
Folate	-0.74	<0.0001	0.02	0.90	0.24	0.24	-0.45	0.02
Hb	-0.06	0.76	-0.32	0.11	-0.44	0.02	0.32	0.10
eGFR	-0.52	0.005	-0.25	0.22	-0.07	0.72	-0.12	0.53
MCV	0.19	0.34	0.19	0.34	0.14	0.48	0.04	0.82
TI	0.17	0.38	-0.20	0.33	-0.04	0.83	0.02	0.93
Resection	0.06	0.75	0.10	0.64	0.10	0.61	-0.12	0.54

Note: *r<sub>s</sub>*, correlation coefficient; tHcy, homocysteine; MMA, methylmalonic acid; Hb, haemoglobin; eGFR, estimated glomerular filtration rate; MCV, mean cell volume; TI,

terminal ileum length; Resection, days post resection.

**Table 3** Correlation between vitamin B<sub>12</sub> status markers and clinical variables in control group (n=27).

	tHcy		Total B <sub>12</sub>		Active B <sub>12</sub>		MMA	
	<i>r<sub>s</sub></i>	<i>P</i>	<i>r<sub>s</sub></i>	<i>p</i>	<i>r<sub>s</sub></i>	<i>p</i>	<i>r<sub>s</sub></i>	<i>P</i>
tHcy	-		-0.26	0.20	-0.32	0.10	0.27	0.18
Total B <sub>12</sub>	-0.26	0.20	-	-	0.51	0.01	0.24	0.25
Active B <sub>12</sub>	-0.32	0.10	0.51	0.01	-	-	-0.13	0.52
MMA	0.27	0.18	0.24	0.25	-0.13	0.52	-	-
Folate	-0.62	0.001	0.43	0.03	0.44	0.03	0.12	0.57
Hb	0.19	0.34	0.05	0.98	-0.00	0.99	-0.03	0.89
eGFR	-0.36	0.08	0.35	0.10	0.34	0.10	-0.08	0.69
MCV	-0.20	0.32	0.46	0.02	0.36	0.07	0.07	0.74

Note: *r<sub>s</sub>*, correlation coefficient; tHcy, homocysteine; MMA, methylmalonic acid; Hb, haemoglobin; eGFR, estimated glomerular filtration rate; MCV, mean cell volume.

## Discussion

This is the first study to assess B<sub>12</sub> status in patients who have undergone a right hemicolectomy for cancer. The study has demonstrated that tHcy concentrations were mildly elevated in patients compared with controls. Over twice as many patients had abnormal tHcy concentrations (>16.0 µmol/L) compared with controls. While vitamin B<sub>12</sub> deficiency results in an elevated plasma tHcy, and is a sensitive marker of vitamin B<sub>12</sub> deficiency, it is not specific to vitamin B<sub>12</sub> deficiency and is a nonspecific marker for many diseases including cardiovascular diseases and dementia [13-15]. Recent studies suggest that mildly elevated concentrations of tHcy may be an indicator of atherosclerosis and cardiovascular disease [14]. However, mildly elevated concentrations (<50 µmol/L) frequently occur in the general population and are influenced by many factors, including folate deficiency, vitamin B<sub>6</sub> deficiency poor renal function, hypothyroidism, lifestyle factors (smoking, alcoholism, diet) age and gender, drug therapy and certain genetic polymorphisms. The main predictors of elevated plasma tHcy concentrations are low folate, vitamin B<sub>12</sub> status or renal impairment [13,14]. Although an inverse relationship exists between tHcy and folate in both patients and controls in this study, all participants, apart from one patient and one control, were defined as folate replete (>2.4 µg/L). Similarly, this study demonstrated an inverse relationship between tHcy and eGFR. Hyperhomocysteinaemia (<50 µmol/L) is known to occur when eGFR falls below 60 mL/min/1.73 m<sup>2</sup> [16]. Furthermore, it has been demonstrated that renal impairment causes an increase in tHcy and MMA concentrations in an aged population (≥ 65 years) [17]. In the present study, six of the ten patients with raised tHcy concentrations exhibited concurrent impaired renal function (eGFR <60 mL/min/1.73 m<sup>2</sup>) whereas four patients had normal renal function (eGFR >60 mL/min/1.73 m<sup>2</sup>). However, the assessment of renal function (eGFR <60 mL/min/ 1.73 m<sup>2</sup>) in this study is based on a single measurement

and it is recommended that diagnosis of chronic kidney disease is recorded over at least three months [18]. On repeat testing some participants with eGFR <60 mL/min/1.73 m<sup>2</sup> may exhibit a higher eGFR and vice versa. Notably, the median age of our population is 77 years and thus an effect on renal function is likely which may in turn compromise the interpretation of tHcy and MMA results. The independent effect of renal function on the measurement of tHcy and MMA was not investigated.

The thyroid function and vitamin B<sub>6</sub> status of this group were not investigated and cannot be ruled out as causes. It is possible that these patients also have cardiovascular disease but details of this co-morbidity were not recorded at recruitment and was not part of the exclusion criteria. Further work is necessary to establish the cause of mildly elevated tHcy in this patient group.

Although the study did not show significant differences in active B<sub>12</sub> concentrations between patients and controls there was an inverse relationship between active B<sub>12</sub> and MMA within the patient cohort which was not observed amongst controls. Due to the small numbers of participants in this study, the independent effect of variables on MMA and B<sub>12</sub> concentrations was not explored.

This study highlights the difficulty in defining B<sub>12</sub> status using various circulating markers. The total B<sub>12</sub> and active B<sub>12</sub> results both demonstrate that a large proportion of patients and controls fall within the indeterminate range. According to recent British Journal of Haematology guidelines, patients with a reduced total B<sub>12</sub> and normal tHcy and MMA do not require any further investigations and are not classified as B<sub>12</sub> deficient [19]. In the current study, further testing using the recommended second-line investigations, MMA or tHcy, revealed that only a quarter of the study participants with indeterminate active B<sub>12</sub> results and only a fifth with indeterminate total B<sub>12</sub> results, may be B<sub>12</sub> deficient. Although many studies recommend these second line investigations



there is currently not a gold standard test available for B<sub>12</sub> status. Recently, active B<sub>12</sub> has been shown to be the best marker of B<sub>12</sub> status in older people (n=700; mean age=81 years) when compared with red cell cobalamin [7]. Furthermore, in this study the indeterminate range was defined as 20-30 pmol/L and anything above that was defined as normal. If these cut-offs are applied to these data then all study participants would be defined as replete despite having elevated MMA and tHcy concentrations, thereby highlighting the importance of establishing local reference ranges due to variations between populations and methodologies. For the present study, the reference ranges for active B<sub>12</sub> recommended by the referral laboratory in London have been used, which may not represent the population in South Wales. It would be useful to establish a local reference range for active B<sub>12</sub>. Thus, further work is necessary before the B<sub>12</sub> status can be accurately determined in our local population and also in cancer patients who have undergone right hemicolectomy.

Of the participants classified as B<sub>12</sub> deficient (determined by either total or active B<sub>12</sub>) none were found to have macrocytosis and/or anemia. Similarly, a Finnish study investigating the prevalence of B<sub>12</sub> deficiency in an elderly population (n=1048; age range: 65-100 years) demonstrated that anemia or macrocytosis did not predict B<sub>12</sub> deficiency and only two of their 97 subjects with B<sub>12</sub> deficiency would have been diagnosed based on these observations [20]. This raises the question of the sensitivity of this approach in the early diagnosis of B<sub>12</sub> deficiency.

The small sample size in this study does not allow a detailed analysis of B<sub>12</sub> status as originally anticipated. These results demonstrate that a high proportion of patients (54%) and controls (48%) are not replete in vitamin B<sub>12</sub>. Whether this is a true representation of the local population needs further investigation and a further larger study would allow a better stratification of study participants into those who are vitamin B<sub>12</sub> deficient or replete. The population (600,000) served by Aneurin Bevan University Health Board come from both rural and suburban areas, with a mix of socioeconomic status. Those living in rural and lower socioeconomic areas may have a limited access to healthcare and as a consequence are more likely to be vitamin B<sub>12</sub> deficient.

In conclusion, this study demonstrates that there are subtle differences between the controls and patients who have undergone a right hemicolectomy for cancer. We recommend that vitamin B<sub>12</sub> status is investigated further using the aforementioned recommended laboratory markers for tissue vitamin B<sub>12</sub> stores in order to understand how terminal ileum excision alters this essential regulatory system. Replenishing vitamin B<sub>12</sub> may improve short and long-term outcomes of patients that have had a right hemicolectomy.

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## References

1. Cancer Research UK [<http://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/bowel-cancer/incidence>.] Accessed on February 2017.
2. National Bowel Cancer Audit Report (2016) The Association of Colorectology of Great Britain and Ireland.
3. Duerksen DR, Fallows G, Bernstein CN (2006) Vitamin B12 malabsorption in patients with limited ileal resection. *Nutrition* 22: 1210-1213.
4. Thompson WG, Wrathell E (1977) The relation between ileal resection and Vitamin B12 absorption. *Can J Surg* 20: 461-464.
5. Behrend C, Jeppersen PB, Mortensen PB (1995) Vitamin B12 absorption after ileorectal anastomosis for Crohns Disease. *Eur J Gastroenterol Hepatol* 7: 397-400.
6. Domstad PA, Choy YC, Kim EE, DeLand FH (1981) Reliability of the Dual Isotope Schilling test for the diagnosis of Pernicious Anaemia or Malabsorption Syndromes. *Am J Clin Pathol* 75: 723-726.
7. Valente E, Scott JM, Per-Magne U, Cunningham C, Casey M, et al. (2011) Diagnostic accuracy of Holotranscobalamin, methylmalonic acid, serum cobalamin and other indicators of tissue Vitamin B12 status in the elderly. *Clin Chem* 57: 856-863.
8. Spence JD (2016) Metabolic vitamin B12 deficiency: a missed opportunity to prevent dementia and stroke. *Nutr Res* 36: 109-116.
9. Hunt A, Harrington D, Robinson S (2014) Vitamin B12 deficiency. *BMJ* 349: 5226.
10. Nexø E, Hørrmann-Lucke E (2011) Holotranscobalamin, a marker of vitamin B12 status: analytical aspects and clinical utility. *Am J Clin Nutr* 94: 359S-365S.
11. Levey AS, Greene T, Kusek J (2000) A simplified equation to predict glomerular filtration rate from serum creatinine. *J Am Soc Nephrol* 11: 155A.
12. Viapath (2017) [[www.viapath.co.uk](http://www.viapath.co.uk)] Accessed on February 2017.
13. Refsum H, Smith AD, Ueland PM, Nexø E, Clarke R, et al. (2004) Facts and recommendations about total homocysteine determinations: an expert opinion. *Clin Chem* 50: 3-32.
14. Moat SJ (2008) Plasma total homocysteine: instigator or indicator of cardiovascular disease? *Ann Clin Biochem* 45: 345-348.
15. McCaddon A, Husdon P, Davies G, Hughes A, William JH, et al. (2001) Homocysteine and cognitive decline in healthy elderly. *Dement Geriatr Cogn Disord* 12: 309-313.
16. Van GC (2006) Why is homocysteine elevated in renal failure and what can be expected from homocysteine-lowering? *Nephrol Dial Transplant* 21: 1161-1166.
17. Loikas S, Koskinen P, Irjala K, Löppönen M, Isoaho R, et al. (2007) Renal impairment compromises the use of total homocysteine

and methylmalonic acid but not total vitamin B12 and holotranscobalamin in screening for vitamin B12 deficiency in the aged. *Clin Chem Lab Med* 45: 197-220.

18. Levey AS, Eckardt KU, Tsukamoto Y, Levin A, Coresh J, et al. (2005) Definition and classification of chronic kidney disease: a position statement from Kidney Disease: Improving Global Outcomes (KDIGO). *Kidney Int* 67: 2089-2100.
19. Devalia V, Hamilton MS, Molloy AM (2014) Guidelines for the diagnosis and treatment of cobalamin and folate disorders. *Br J Haem* 166: 496-513.
20. Loikas S, Koskinen P, Irjala K, Löppönen M, Isoaho R, et al. (2007) Vitamin B12 deficiency in the aged: a population-based study. *Age Ageing* 36: 177-183.