

## Systematic Review

# Plasma total homocysteine status of vegetarians compared with omnivores: a systematic review and meta-analysis

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### Abstract

There is strong evidence indicating that elevated plasma total homocysteine (tHcy) levels are a major independent biomarker and/or a contributor to chronic conditions, such as CVD. A deficiency of vitamin B<sub>12</sub> can elevate homocysteine. Vegetarians are a group of the population who are potentially at greater risk of vitamin B<sub>12</sub> deficiency than omnivores. This is the first systematic review and meta-analysis to appraise a range of studies that compared the homocysteine and vitamin B<sub>12</sub> levels of vegetarians and omnivores. The search methods employed identified 443 entries, from which, by screening using set inclusion and exclusion criteria, six eligible cohort case studies and eleven cross-sectional studies from 1999 to 2010 were revealed, which compared concentrations of plasma tHcy and serum vitamin B<sub>12</sub> of omnivores, lactovegetarians or lacto-ovovegetarians and vegans. Of the identified seventeen studies (3230 participants), only two studies reported that vegan concentrations of plasma tHcy and serum vitamin B<sub>12</sub> did not differ from omnivores. The present study confirmed that an inverse relationship exists between plasma tHcy and serum vitamin B<sub>12</sub>, from which it can be concluded that the usual dietary source of vitamin B<sub>12</sub> is animal products and those who choose to omit or restrict these products are destined to become vitamin B<sub>12</sub> deficient. At present, the available supplement, which is usually used for fortification of food, is the unreliable cyanocobalamin. A well-designed study is needed to investigate a reliable and suitable supplement to normalise the elevated plasma tHcy of a high majority of vegetarians. This would fill the gaps in the present nutritional scientific knowledge.

**Key words:** Hyperhomocysteinaemia: Vitamin B<sub>12</sub>: Vegetarians: Omnivores

There are approximately four million vegetarians within the UK population<sup>(1)</sup>. In addition 5% of British adults are practising semi-vegetarians, whose diet contains a greatly reduced intake of products of animal origin<sup>(2)</sup>. Worldwide, there are 75 million vegetarians by choice and 1450 million by necessity<sup>(3)</sup>. This agrees with the Foods Standards Agency<sup>(4)</sup> approximation of 25% of the world's population consuming a largely vegetarian diet. The most commonly known vegetarians are vegan, lactovegetarian (LV) and lacto-ovovegetarian (LOV).

Hyperhomocysteinaemia (>15 µmol/l, as defined by Ravaglia *et al.*<sup>(5)</sup>) has been shown to be linked with chronic conditions, among which is CVD<sup>(6,7)</sup>. Other studies have shown that CHD is linked to homocysteine concentrations, with a substantial risk occurring at >10 µmol/l plasma total

homocysteine (tHcy)<sup>(8,9)</sup>. Furthermore, each 5 µmol/l increase in plasma tHcy is associated with an approximate 20% increased risk of CHD events<sup>(6,7)</sup>, irrespective of the diet. The present review sets out to determine the homocysteine and vitamin B<sub>12</sub> status of vegetarians compared with omnivores, as they may be a group of the population who may have the potential to be at greater risk than omnivores to these homocysteine-related diseases. This is due to the lack of intake of animal produce, the only natural abundant source of vitamin B<sub>12</sub>, whose deficiency can raise homocysteine levels<sup>(10,11)</sup>. Vitamin B<sub>12</sub> is required in the important remethylation pathway, where homocysteine is remethylated to methionine in a reaction catalysed by the enzyme methionine synthase and the cofactor vitamin B<sub>12</sub><sup>(12)</sup>, but only in its

**Abbreviations:** LV, lactovegetarian; LOV, lacto-ovovegetarian; tHcy, total homocysteine; THF, 5-methyl tetrahydrofolate.

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methylcobalamin form<sup>(13)</sup>. Homocysteine acquires a methyl group from 5-methyl tetrahydrofolate (THF), which is catalysed from 5,10-methyleneTHF by the enzyme methylenetetrahydrofolate reductase and folic acid/folate from the diet, which enters the remethylation pathway as THF, via dihydrofolate acid, which has been reduced to THF by the enzyme dihydrofolate reductase. The exact pathomechanisms of cobalamin deficiency that cause the typical clinical symptoms of vitamin B<sub>12</sub> deficiency, especially the neurological symptoms, in human subjects have not been fully clarified. The methyl folate trap hypothesis<sup>(14–16)</sup> has been widely accepted over decades, despite the difficulty in testing the theory in any meaningful way. The methyl trap hypothesis proposes that due to a vitamin B<sub>12</sub> deficiency, folate can be trapped as methylfolate, which is metabolically inactive. This is due to the fact that vitamin B<sub>12</sub> is required for the transfer of the methyl group from 5-methylTHF to form THF, so that it can return to the tetrahydrofolate pool for conversion to 5,10-methyleneTHF. As the transfer of the methyl group of 5-methylTHF to homocysteine is impaired in vitamin B<sub>12</sub> deficiency, it results in a rise in homocysteine levels<sup>(17,18)</sup>.

The RDA for vitamin B<sub>12</sub> is 2.5 µg<sup>(19)</sup>, of which the body stores considerable amounts (several mg) in the liver. The body recycles approximately 75% of vitamin B<sub>12</sub> it uses; serum vitamin B<sub>12</sub> starts to decline and plasma tHcy rises when the absorption of the ingested vitamin B<sub>12</sub> input is less than that dissipated by the body<sup>(20)</sup>. Thus, a delay of 5–10 years may separate the beginning of a vegetarian diet and the onset of deficiency symptoms that usually occur when serum vitamin B<sub>12</sub> is reduced to below 150 pmol/l, which marks the onset of pernicious anaemia<sup>(21)</sup>.

It is also noted that cell-surface receptors located in the ileum require free Ca to enable the vitamin B<sub>12</sub> absorption – intrinsic factor complex to aid absorption of vitamin B<sub>12</sub><sup>(22–24)</sup>.

Lack of Ca in the vegetarian diet could, therefore, inhibit vitamin B<sub>12</sub> absorption<sup>(22–24)</sup>. Prolonged Fe deficiency damages the gastric mucosa and promotes atrophic gastritis and gastric atrophy, including loss of gastric acid and intrinsic factor secretion and, therefore, diminished vitamin B<sub>12</sub> absorption. As vegetarians have reduced Fe intake<sup>(25–27)</sup>, this would cause vitamin B<sub>12</sub> deficiency<sup>(28)</sup>. Furthermore, vitamin B<sub>12</sub> is excreted in the presence of high levels of soluble fibre (such as pectin), probably via an effect on the enterohepatic cycle of vitamin B<sub>12</sub>, a common feature of vegetarian diets<sup>(29)</sup>. Furthermore, vegetarian diets contain high levels of *n*-6 PUFA, whilst they are low in *n*-3 PUFA. This imbalance, together with inherent low vitamin B<sub>12</sub> levels and consequential high concentrations of plasma tHcy, can be shown to have a thrombotic tendency that raises the risk of developing CVD<sup>(30)</sup>.

### Hypothesis and objective

The hypothesis is that there is a correlation between levels of plasma tHcy and the intake of dietary animal produce, the only natural abundant source of vitamin B<sub>12</sub>.

The main objective of the present systematic review and meta-analysis is, therefore, to assess the plasma tHcy and serum vitamin B<sub>12</sub> status of LV–LOV and vegans, as compared

with omnivores, from a wide range of cohort and cross-sectional published studies that have met the set criteria.

## Materials and methods

### Electronic searches

The search engines selected were PubMed, as it contains entries from MEDLINE, EMBASE, JAMA, BMJ, Cochrane Databases and Lancet, together with Science Direct, ACP Journal Club, CCTR, AMED, Highwire Press and EBSCO host databases. A search for systematic reviews, meta-analyses, cohort case studies, cross-sectional studies and randomised controlled trials was carried out using the search terms ‘Hyperhomocysteinemia’; ‘Vitamin B<sub>12</sub>’; ‘Omnivores and vegetarians’; and ‘Supplementation with vitamin B<sub>12</sub> to normalise homocysteine in vegetarians’; this revealed 443 entries for studies undertaken during the period from January 1999 to June 2011.

### Participants

In the studies examined, omnivores were defined as individuals who consumed both plant and animal products. LV were defined as individuals who did not consume animal produce, but consumed dairy products. LOV had the same diet as LV, but they consumed eggs too. Vegans were defined as individuals who abstained from all types of animal products and semi-vegetarians were defined as individuals who occasionally included animal products in their diet.

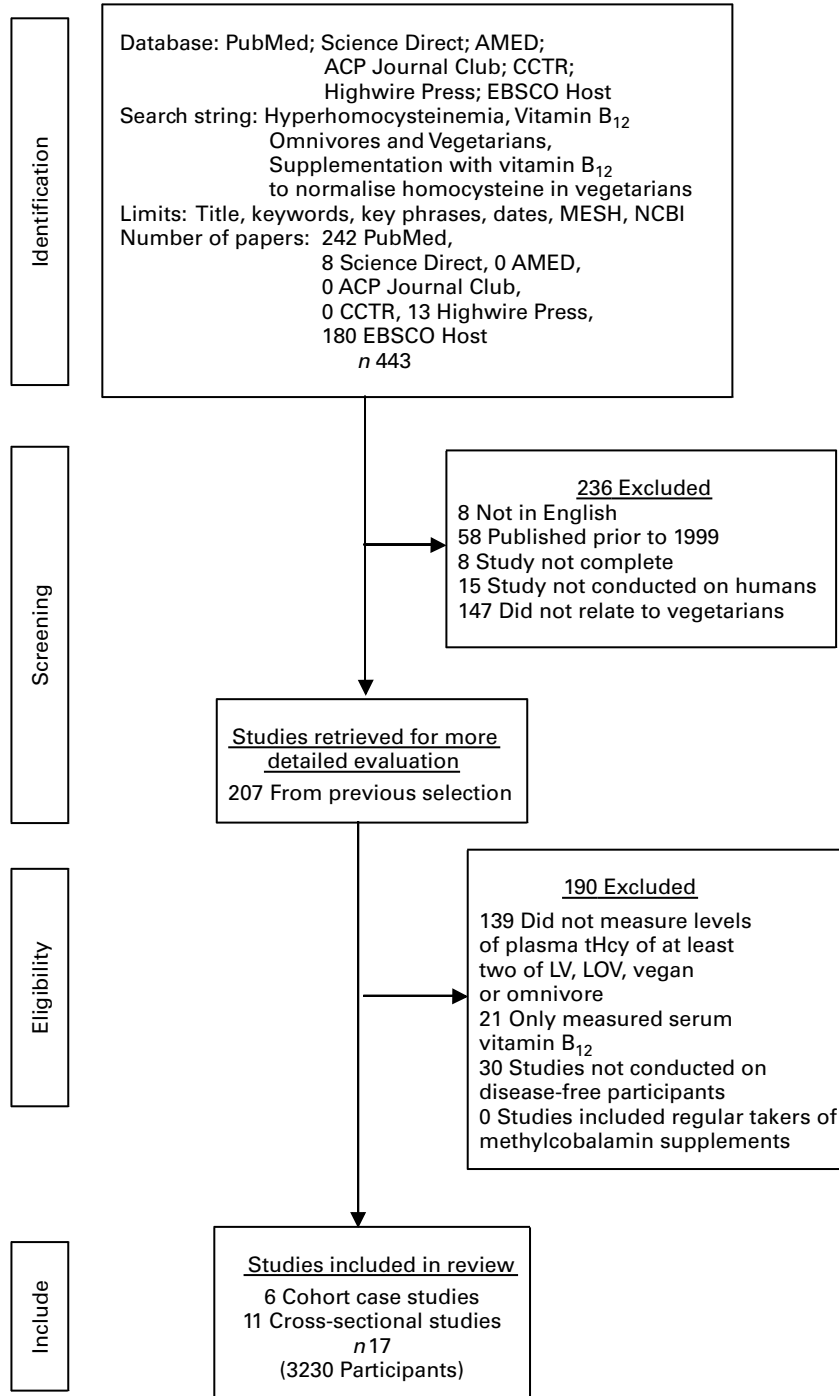
### Inclusion and exclusion criteria

The flow chart in Fig. 1 outlines the initial inclusion and exclusion criteria employed in the selection of six cohort case studies and eleven cross-sectional studies; this was followed by these studies being finally assessed by one author and checked by another for methodological validity employing standardised data extraction tools from JBI000308<sup>(31)</sup> with any disagreements being resolved through discussion with a third reviewer. All initially screened studies met these requirements and are included in the present systematic review and meta-analysis, and summarised in Table 1.

### Statistical analyses

Data from the selected seventeen studies in the vast majority of cases have been calculated as mean values for each diet group. In the case of the small number of cases that employed median values, it has been assumed in the calculations that these are approximately equal to the mean value, and that, in the case of two studies, the small number of vegans has been included in the LV–LOV group. As the number (*n*) is <30 for the group of the studies, comparison between groups has been undertaken by Student’s two-tailed unpaired test to determine the significant difference between the values of plasma tHcy and serum vitamin B<sub>12</sub> for LV–LOV and vegans against omnivores<sup>(32)</sup>. Table 2 summarises the calculated values.





**Fig. 1.** Flow chart. Initial inclusion and exclusion criteria for selected studies for plasma total homocysteine (tHcy) and serum vitamin B<sub>12</sub> status of omnivores, lactovegetarians (LV) or lacto-ovo vegetarians (LOV) and vegans.

## Results

Of a total of 443 entries, the search revealed six cohort case studies and eleven cross-sectional studies, as summarised in Table 1.

Table 2 demonstrates that the primary outcome of the meta-analysis is that an inverse relationship exists between plasma tHcy and serum vitamin B<sub>12</sub> for all three diets, indicating

that vegans have the highest mean plasma tHcy value of 16.41 (SD 4.80) μmol/l as well as the lowest mean serum vitamin B<sub>12</sub> value of 172 (SD 59) pmol/l.

LV–LOV exhibited a mean plasma tHcy value of 13.91 (SD 3.15) μmol/l and a mean serum vitamin B<sub>12</sub> value of 209 (SD 47) pmol/l. Omnivores recorded a mean plasma tHcy value of 11.03 (SD 2.89) μmol/l and a mean serum vitamin B<sub>12</sub> value of 303 (SD 72) pmol/l. Fig. 2 indicates the

**Table 1.** Details of the selected studies of plasma total homocysteine (tHcy) and serum vitamin B<sub>12</sub> status among omnivores, lactovegetarians or lacto-ovovegetarians and vegans (1999–2010) (Mean values and standard deviations; medians, 5th–95th percentiles and 25th–75th percentiles; geometric mean values and 95 % confidence intervals)

Study, date of publication and sex	Volunteers (n)	Average age (years)	Duration of being vegetarian (years)	Plasma tHcy (μmol/l)						Serum vitamin B <sub>12</sub> (pmol/l)							
				Mean	SD	Median	5th–95th percentiles	25th–75th percentiles	95 % CI	Mean	SD	Median	5th–95th percentile	25th–75th percentiles	95 % CI		
Haddad <i>et al.</i> (1999) <sup>(34)</sup>																	
Omnivores*	20	33.5		8.0	1.9					313	99						
Vegans*	25	36.0	> 1	7.9	1.5					312	125						
Mann <i>et al.</i> (1999) <sup>(39)</sup>																	
Omnivores†	18	34.2		11.0	2.5					403	169						
Lactovegetarians or lacto-ovovegetarians†	43	34.9	Not stated	15.8	9.3					211	98						
Vegans†	18	33.0	Not stated	19.2	10.7					145	68						
Krajcovicova-Kudlackova <i>et al.</i> (2000) <sup>(40)</sup>																	
Omnivores‡	59	40.9		10.2	0.3					345	8.2						
Lactovegetarians or lacto-ovovegetarians‡	62	35.1	8.5 Mean	13.2	0.3					215	5.1						
Vegans‡	32	41.5	8.5 Mean	15.8	0.9					140	4.9						
Herrmann <i>et al.</i> (2001) <sup>(41)</sup>																	
Omnivores‡	44	23.0				9.8	5.9–16.7					276	172–406				
Lactovegetarians or lacto-ovovegetarians‡	34	22.0	> 1			11.0	5.7–20.8					253	153–376				
Vegans‡	7	22.0	> 1			15.2	9.3–18.5					217	153–438				
Refsum <i>et al.</i> (2001) <sup>(45)</sup>																	
Omnivores*	126	41.0				19.4	9.7–45.7					161	62–492				
Lactovegetarians or lacto-ovovegetarians*	78	41.0	Not stated			22.0	9.6–48					124	66–625				
Hung <i>et al.</i> (2002) <sup>(50)</sup>																	
Omnivores§	45	38.0		8.6	2.0					404	139						
Lactovegetarians or lacto-ovovegetarians§	45	38.0	> 2	11.2	4.3					208	127						
Cappuccio <i>et al.</i> (2002) <sup>(33)</sup>																	
Omnivores†	583	50.7		11.2													
Lactovegetarians or lacto-ovovegetarians†	46	50.7	Not stated	15.1													
Omnivores§	669	50.7		8.9													
Lactovegetarians or lacto-ovovegetarians‡	92	50.7	Not stated	11.5													
Bissoli <i>et al.</i> (2002) <sup>(35)</sup>																	
Lactovegetarians or lacto-ovovegetarians*	14	48.5	> 5	17.4	11.1							164	57				
Vegans	31	45.8	> 5	26.9	24.1							155	74				
Huang <i>et al.</i> (2003) <sup>(43)</sup>																	
Omnivores‡	32	22.9		9.8													
Lactovegetarians or lacto-ovovegetarians‡	37	28.9	> 1	13.2													
Herrmann <i>et al.</i> (2003) <sup>(36)</sup>																	
Omnivores*	79	46.0				8.8	5.5–16.1					287	190–471				
Lactovegetarians or lacto-ovovegetarians*	53	40.0	> 1			10.9	6.8–28.2					179	124–330				
Vegans*	12	39.0	> 1			14.3	6.5–52.1					126	92–267				

Table 1. Continued

Study, date of publication and sex	Volunteers (n)	Average age (years)	Duration of being vegetarian (years)	Plasma tHcy (μmol/l)						Serum vitamin B <sub>12</sub> (pmol/l)					
				Mean	SD	Median	5th–95th percentiles	25th–75th percentiles	95 % CI	Mean	SD	Median	5th–95th percentile	25th–75th percentiles	95 % CI
Waldmann <i>et al.</i> (2003) <sup>(46)</sup>															
Lactovegetarians or lacto-ovovegetarians*	45	44.6	> 1			12.3	4.6–23.6			185		97.6–689			
Vegans*	86	43.8	> 1			13.4	6.0–82.5			122		71.2–276			
Koebnick <i>et al.</i> (2005) <sup>(37)</sup>															
Omnivores‡	109	44.5				14.7		12–18.3		175			142–250		
Lactovegetarians or lacto-ovovegetarians*	38	44.5	> 1			17.1		13–20.2		143			121–176		
Vegans*	39	44.5	> 1			18.5		13.5–29		126			88–182		
Su <i>et al.</i> (2006) <sup>(47)</sup>															
Omnivores§	61	57.7			9.0	2.1				380	199				
Lactovegetarians or lacto-ovovegetarians§	57	59.2	> 5		11.0	3.3				265	179				
Majchrzak <i>et al.</i> (2006) <sup>(42)</sup>															
Omnivores*	40	38.4			12.2	5.6				252	83				
Lactovegetarians or lacto-ovovegetarians*	36	34.2	< 1 to > 5							239	99				
Vegans*	42	30.7	< 1 to > 5		14.0	5.4				203	102				
Karabudak <i>et al.</i> (2008) <sup>(48)</sup>															
Omnivores§	26	27.4			16.5	8.2				269	235				
Lactovegetarians or lacto-ovovegetarians§	26	29.0	10.5 ± 6.7		10.8	3.7				201	137				
Yen <i>et al.</i> (2010) <sup>(38)</sup>															
Omnivores*	28	35.9			12.6	6.0				359	138				
Lactovegetarians or lacto-ovovegetarians* †	21	34.8	> 0.5		9.6	2.2				307	267				
Krivosikova <i>et al.</i> (2010) <sup>(49)</sup>															
Omnivores§	131	40.8			10.4	5.7				306	137				
Lactovegetarians or lacto-ovovegetarians§	141	41.9	Not stated		16.5	5.6				247	161				

\* Mixed population of adult volunteers.

† Male adult volunteers only.

‡ Sex of volunteers not stated.

§ Female adult volunteers only.

|| Geometric mean.

\* Combined measured levels of plasma tHcy and serum vitamin B<sub>12</sub> of lactovegetarians or lacto-ovovegetarians and vegans.

**Table 2.** Plasma total homocysteine (tHcy) and serum vitamin B<sub>12</sub> levels of lactovegetarians or lacto-ovo vegetarians and vegans compared with omnivores from the selected seventeen studies shown in Table 1 (study by Cappuccio *et al.*<sup>(33)</sup> omitted) (Mean values and standard deviations)

Diet	Plasma tHcy (μmol/l)				Serum vitamin B <sub>12</sub> (pmol/l)			
	Mean	SD	n	P	Mean	SD	n	P
Omnivores	11.03	2.89	14		303	72	14	
Lactovegetarians or lacto-ovovegetarians	13.91	3.15	15	<0.025	209	47	15	<0.005
Vegans	16.41	4.80	9	<0.005	172	59	9	<0.005

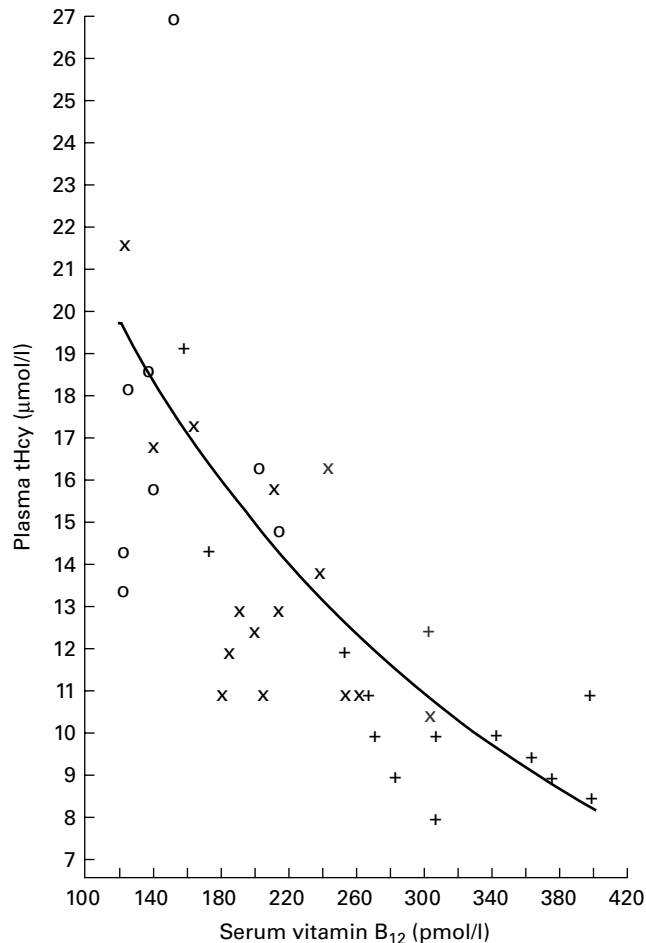
relationship between plasma tHcy and serum vitamin B<sub>12</sub> for the three diets.

### Statistical heterogeneity

The null hypothesis states that the mean values of plasma tHcy and serum vitamin B<sub>12</sub> for omnivores, LV–LOV and vegans are homogeneous. Table 3 reports the results of an ANOVA, which demonstrates that the null hypothesis can be rejected.

### Discussion

A total of fifteen of the seventeen selected studies that met the inclusion and exclusion criteria show a good agreement that serum vitamin B<sub>12</sub> and plasma tHcy exhibit an inverse relationship. The study by Cappuccio *et al.*<sup>(33)</sup> did not monitor serum vitamin B<sub>12</sub> levels. The study by Haddad *et al.*<sup>(34)</sup> concluded that, statistically, vegans had similar plasma tHcy to omnivores (i.e. 8.0 against 7.9 μmol/l, respectively) and serum vitamin B<sub>12</sub> levels (i.e. 313 against 312 pmol/l, respectively). In this case, it was noted that 36% of the participating vegans were users of vitamin B<sub>12</sub> supplements, although the type, dosage and frequency of usage were not reported. Nevertheless, this could confound the statistics, which have given a result that is incompatible with the other fifteen studies. Furthermore, a small proportion of LV–LOV and vegans were found to be consuming vitamin B<sub>12</sub> supplements and/or consuming vitamin B<sub>12</sub>-fortified foods in the studies conducted by Bissoli *et al.*<sup>(35)</sup>, Herrmann *et al.*<sup>(36)</sup> and Koebnick *et al.*<sup>(37)</sup>. None of these studies recorded details regarding type, dosage and frequency of consumption. The conclusion reached by the respective researchers was that fortification does not lower plasma tHcy or increase serum vitamin B<sub>12</sub> levels significantly. The remaining studies stated that no vitamin B<sub>12</sub> supplements had been used by the participants. Yen *et al.*<sup>(38)</sup> concluded that vegetarian parents and their preschool children had lower vitamin B<sub>12</sub> intake than omnivorous parents and their preschool children, but had similar vitamin B<sub>12</sub> and homocysteine concentrations. As far as the adults are concerned, these results are incompatible with the observations of six studies that compared LV–LOV, vegan and omnivores' serum vitamin B<sub>12</sub> and plasma tHcy levels<sup>(36,37,39–42)</sup>. Huang *et al.*<sup>(43)</sup> concluded that vegetarians have lower vitamin B<sub>12</sub> status than omnivores, leading to raised plasma tHcy, and that vitamin B<sub>6</sub> and folate have little effect on plasma homocysteine concentration when individuals have adequate vitamin B<sub>6</sub> and folate status. Kluijtmans *et al.*<sup>(10)</sup> and Selhub<sup>(11)</sup> demonstrated that hyperhomocysteinaemia can be caused by a deficiency of folate. They also demonstrated that, normally, homocysteine elevation is much less affected in cases of vitamin B<sub>6</sub> deficiency. However, Majchrzak *et al.*<sup>(42)</sup> have shown that in vegetarian diets and, particularly, in vegan diets, which contain relatively high levels of folate, folate deficiency is unlikely to occur, whereas omnivore diets are more predisposed to this. An exception to this is possibly seen in India, where traditionally folate deficiency has been linked to poverty, which may cause problems, with 33% of the population being vegetarians by necessity<sup>(44)</sup>. There is strong



**Fig. 2.** Correlation between plasma total homocysteine (tHcy) and serum vitamin B<sub>12</sub> for omnivores, lactovegetarians (LV) or lacto-ovovegetarians (LOV) and vegans, with median values approximated to be equal to mean values of five studies<sup>(36,37,41,45,46)</sup> and combined measured levels of plasma tHcy and serum B<sub>12</sub> of LV or LOV and vegans of two studies<sup>(38,43)</sup> from 1999 to 2010 (study by Cappuccio *et al.*<sup>(33)</sup> excluded) taken from Table 1.  $Y = 24.57 e^{-0.003x}$  ( $R^2$  0.598). +, Omnivores; x, LV–LOV; o, vegans.

**Table 3.** ANOVA table for differences of plasma total homocysteine and serum vitamin B<sub>12</sub> between omnivores and vegans and omnivores and lactovegetarians or lacto-ovovegetarians\*

	Sum of squares	df	Mean square	P	F <sub>α, 2, 35</sub>	Outcome
<b>Plasma total homocysteine</b>						
Between groups	164.124	2	82.062	6.033	3.267	Significant: P<0.01
Within groups	476.087	35	13.602			
Total	640.211	37				
<b>Serum vitamin B<sub>12</sub></b>						
Between groups	112.389	2	56.195	14.42	3.267	Significant: P<0.001
Within groups	136.349	35	3.896			
Total	248.738	37				

\* Mean values utilised from Table 2.

evidence, with a significance of  $P < 0.005$  from four studies that, compared with omnivores, a large proportion of vegans develop hyperhomocysteinaemia ( $> 15 \mu\text{mol/l}$  plasma tHcy) and serum vitamin B<sub>12</sub> deficiency ( $\leq 150 \text{pmol/l}$ )<sup>(37,39-41)</sup>. Furthermore, a significant proportion of LV-LOV subjects in the study conducted by Koebnick *et al.*<sup>(37)</sup> showed a hyperhomocysteinaemia condition, with a strong significance of  $P < 0.001$ . A total of ten studies<sup>(35,40-43,46-50)</sup> reported that vegans and/or LV-LOV were found to have plasma tHcy  $> 10 \mu\text{mol/l}$  and serum vitamin B<sub>12</sub> of  $> 150 \text{pmol/l}$  (i.e. not deficient<sup>(21)</sup>), although vegan and LV-LOV levels of serum vitamin B<sub>12</sub> were substantially lower than omnivores, with mean values of 172 and 209 against 303 pmol/l, respectively (Table 2). This was generally in accordance with studies conducted by Joosten *et al.*<sup>(51)</sup> and Herrmann *et al.*<sup>(52)</sup>.

Refsum *et al.*<sup>(45)</sup> reported that, in India, both omnivores and LV-LOV have high plasma Hcy levels (i.e. 19.4 *v.* 22.0  $\mu\text{mol/l}$ , respectively), indicating hyperhomocysteinaemia together with low serum vitamin B<sub>12</sub> levels (i.e. 161.0 *v.* 124.0 pmol/l, respectively). It is, however, noted that even the diet of non-vegetarians in India contains only low proportions of animal produce and hence relatively low amounts of vitamin B<sub>12</sub><sup>(52)</sup>. Also, it is noted that a high proportion of the Indian population is expected to have, in addition, folate deficiency. This could be a contributing factor for the high levels of plasma tHcy and low levels of serum vitamin B<sub>12</sub> in Indian omnivores. Furthermore, most vegetarians and omnivores in India begin consuming essentially a vegetarian diet as infants, which leads to low vitamin B<sub>12</sub> intake, with the only source of vitamin B<sub>12</sub> coming from bacterial-contaminated food, for most of their lives<sup>(55)</sup>. India has large proportions of its population who suffer from malnutrition, tropical sprue and gastrointestinal infections, which often result in malabsorption<sup>(54-56)</sup>. It would seem reasonable to deduce that the high prevalence of vitamin B<sub>12</sub> deficiency accompanied by elevated plasma tHcy can only be expected for both omnivores and LV-LOV in India.

The examined studies took steps to eliminate possible well-known confounding factors that may distort the results and were appropriately adjusted for factors such as smoking, age and sex. However, there is a minimal risk of distortion due to inter-assay and inter-population bias and variability in the present study. It can be clearly observed from Table 2 that there is an inverse relationship between plasma tHcy

and serum vitamin B<sub>12</sub>. Moreover, statistical evidence in Table 2 indicates that vegans have the highest mean values of plasma tHcy and the lowest mean levels of serum vitamin B<sub>12</sub>. LV-LOV show intermediate levels, whereas omnivores exhibit high level of serum vitamin B<sub>12</sub> and the lowest levels of plasma tHcy. This is compatible with work done by Herbert & Das<sup>(21)</sup>. Studies undertaken by Gilsing *et al.*<sup>(57)</sup>, who researched British male omnivores, LV-LOV and vegans, found that 226 omnivores had mean serum vitamin B<sub>12</sub> levels of 281 (95% CI 270, 292) pmol/l, 231 LV-LOV had mean serum vitamin B<sub>12</sub> levels of 182 (95% CI 175, 189) pmol/l and 232 vegans had mean serum vitamin B<sub>12</sub> levels of 122 (95% CI 117, 127) pmol/l. Furthermore, work done by Herbert & Das<sup>(21)</sup>, who studied vitamin B<sub>12</sub> deficiency of LV, LOV, vegans and semi-vegetarians from the American Vegetarian Society, found that 92% of the vegans, 64% of the LV, 47% of the LOV and 20% of semi-vegetarians had serum vitamin B<sub>12</sub> levels of  $\leq 150 \text{pmol/l}$ , which indicates vitamin B<sub>12</sub> deficiency<sup>(21)</sup>.

In the research carried out by Ueland *et al.*<sup>(6)</sup>, Humphrey *et al.*<sup>(7)</sup>, Malinow *et al.*<sup>(8)</sup> and Ubbink<sup>(9)</sup>, it was demonstrated that a substantial risk of developing CHD exists at a plasma tHcy level of  $> 10 \mu\text{mol/l}$  and that, furthermore, each 5  $\mu\text{mol/l}$  increase in plasma tHcy is associated with an approximately 20% increase risk of CHD events. This, together with the fact that the present study indicates that there is an inverse relationship between plasma tHcy and serum vitamin B<sub>12</sub>, is not unreasonable to deduce that these danger levels will be breached by some vegetarians well before they reach the deficiency level of serum vitamin B<sub>12</sub> ( $\leq 150 \text{pmol/l}$ ) and symptoms of pernicious anaemia usually occur<sup>(21)</sup>. Levels at which this could occur apply to all vegetarian groups, with exception of Haddad *et al.*<sup>(34)</sup>, as can be observed in Table 1. Meta-analyses conducted by the Homocysteine Studies Collaboration<sup>(58)</sup> and Wald *et al.*<sup>(59)</sup> have demonstrated that lowering homocysteine concentrations by 3  $\mu\text{mol/l}$  substantially reduces the risk of CVD. Moreover, Ward *et al.*<sup>(60)</sup> showed that there is a benefit to health in reducing the risk of primary CVD by lowering homocysteine levels. In contrast, The Heart Outcome Prevention Evaluation (HOPE 2) Investigation<sup>(61)</sup> found that supplements combining vitamin B<sub>12</sub> and folic acid did not reduce the risk of major secondary cardiovascular events in patients with vascular disease.

A further finding is that the mean overall homocysteine level of vegans shown in Table 2 of 16.41 (SD 4.80)  $\mu\text{mol/l}$  ( $P < 0.005$ ) and mean serum vitamin B<sub>12</sub> of 172 (SD 59)  $\text{pmol/l}$  ( $P < 0.005$ ) indicates that most vegans can be classified as being likely to suffer from hyperhomocysteinaemia due to a deficiency of vitamin B<sub>12</sub> that will increase their risk of developing CVD. Moreover, LV–LOV with a mean overall homocysteine level of 13.91 (SD 3.15)  $\mu\text{mol/l}$  ( $P < 0.025$ ) and mean serum vitamin B<sub>12</sub> of 209 (SD 47)  $\text{pmol/l}$  ( $P < 0.005$ ) also have an increased risk of developing CVD. Furthermore, omnivores from the results recorded in the present review (mean plasma tHcy 11.03 (SD 2.89)  $\mu\text{mol/l}$ ) can be considered generally to have a borderline increased risk of developing homocysteine-related CVD, probably due to inadequate status of folate<sup>(42)</sup>. Statistical tests (independent samples *t* tests and ANOVA) showed a significant difference in mean levels of tHcy and serum vitamin B<sub>12</sub> between omnivores, LV–LOV and vegans. Whilst the diets of some vegetarians are aimed at the well-documented benefits of promoting health, due to the restriction or absence of food from animal origin, this as far as CVD is concerned is probably due to reduced saturated fat, lower total serum cholesterol levels, lower prevalence of obesity and slightly lower blood pressure, as compared with omnivores. However, this may not negate the risk of vegetarians with elevated plasma tHcy being susceptible to homocysteine-related CVD, as indicated by Ueland *et al.*<sup>(6)</sup>, Humphrey *et al.*<sup>(7)</sup>, Malinow *et al.*<sup>(8)</sup> and Ubbink<sup>(9)</sup>. The present review reveals that there is only poor evidence available of vegetarians consuming vitamin B<sub>12</sub> supplements and/or vitamin B<sub>12</sub>-fortified food and beverages. However, supplements, fortified food and beverages normally contain the less efficient cyanocobalamin form of vitamin B<sub>12</sub>, which when it enters the bloodstream must be converted to methylcobalamin<sup>(62)</sup>, the only form of vitamin B<sub>12</sub> that has a methyl donor that is required to neutralise homocysteine<sup>(63)</sup>. It takes 4–9 weeks for this conversion to take place<sup>(64)</sup>, assuming there are no disruptions by genetic factors, age-related problems and metabolic obstacles that may be present. Furthermore, research suggests that vitamin B<sub>12</sub> that is not dissolved in the mouth will not (up to 88%) be absorbed<sup>(65)</sup>, due to the lack of R-binder mostly obtained from saliva, which is required to start the absorption process. The aforementioned study indicates that supplementation with cyanocobalamin can be poorly absorbed, which will have little or no effect on raising vitamin B<sub>12</sub> levels.

A well-designed study is needed to investigate supplementary methylcobalamin by, for example, a 1 mg lozenge dissolved in the mouth (that can bypass the above potential problems), and takes advantage of absorption by mediated intrinsic factor, non-intrinsic-mediated diffusion and sublingual intake and on its effects on elevated homocysteine levels of vegetarians, who may have a resultant susceptibility to hyperhomocysteinaemia-related diseases. This would fill gaps in present nutritional scientific knowledge.

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