The individual negative charges within the fibre do not extend over great distances as they are neutralized by an electrical double layer containing an excess of cations (e.g. Na^+). The fibre is therefore freely permeable to anions so long as the number of free carboxyl groups is small, as is shown by the fact that with cyanide-treated wool, in which the membrane has been opened up, the rate of chlorination is the same at pH 8 as at pH 2. At pH 10 electrical interaction between the anions and the wool begins to be detectable and the rate of chlorination of cyanide-treated wool decreases.

SUMMARY

1. The kinetics of the reaction of wool with aqueous chlorine solution of pH less than 8 are explained by the uniform diffusion of chlorine or hypochlorous acid through the swollen fibres. It has been shown that this process is not rate-determining in solutions of pH greater than 8.

2. The form of the kinetic curve, the effect of various pretreatments on the rate, and the temperature coefficient of the process, all show that the alkaline reaction is not controlled by the actual oxidation process, but can be interpreted in terms of diffusion across a surface barrier.

3. Recent morphological researches on wool fibres have established the existence of two membranes, one of which, the epicuticle, is situated on the extreme outer surface, whilst the other forms part of the cuticle and is referred to as the subcuticle. It is shown that the presence of the epicuticle does not affect the rate of diffusion of the hypochlorite ion. In alkaline solutions the negatively charged subcuticle retards the penetration of anions, so that diffusion through this membrane determines the overall rate of reaction.

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The Biosynthesis of Choline Methyl Groups by the Rat

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It has been known for some time that the supply of choline or betaine to a methionine-free diet enables the white rat to use homocystine as the sole sulphur-containing amino-acid for growth purposes (du Vigneaud, Chandler, Moyer & Keppel, 1939). This effect has been shown to be due to the utilization of the methyl groups of choline for the biological synthesis of methionine from homocystine (Simmonds, Cohn, Chandler & du Vigneaud, 1943). The reverse reaction, i.e. the transfer of the methyl group

of methionine to choline, also occurs (du Vigneaud, Cohn, Chandler, Schenk & Simmonds, 1941). The mechanism of the transfer of labile methyl groups has been elucidated by feeding methionine containing deuterium and ^{14}C in the methyl group. The choline methyl groups were found to contain both isotopic tracers in the same ratio as in the methionine fed, demonstrating the transfer of the methyl group as such (Keller, Rachele & du Vigneaud, 1949).

Recently it has been shown, by feeding methionine labelled with ^{14}C in the methyl group, that labile methyl groups are rapidly oxidized to carbon dioxide by the intact rat (Mackenzie, Chandler, Keller, Rachele, Cross & du Vigneaud, 1949). When choline, labelled with ^{14}C in the methyl groups, was administered to rats, the tracer was found in the β -position of serine (Sakami, 1949*a*) suggesting that formate is an intermediate in the oxidation of labile methyl groups, since the β -carbon atom of serine can arise by condensation of formate and glycine *in vivo* (Sakami, 1948).

It was therefore of some interest to investigate whether the formation of choline methyl groups from simple precursors by a reverse reaction of the above oxidation can occur. Sodium formate and methanol, labelled with ^{14}C , were chosen as two easily accessible one-carbon compounds whilst α -labelled glycine and β -labelled serine were considered to be likely physiological precursors of active one-carbon compounds. *In vitro* work with liver slices had shown that formate is produced from the α -carbon atom of glycine (Siekevitz, Winnick & Greenberg, 1949), and after completion of this work it was reported that both the α -carbon atom of glycine and the β -carbon atom of serine give rise to formaldehyde and formate (Siekevitz & Greenberg, 1950).

A preliminary communication was given by Arnstein (1950*a*).

EXPERIMENTAL

Animals and diet. Except in Exp. 1, where albino rats of Institute strain were used, all the animals were Wistar strain rats supplied by Dr K. Coward, Pharmaceutical Society.

The animals were kept on Institute stock diet of the following composition: wholemeal flour, 46%; Sussex ground oats, 40%; fish meal, 8%; dried skimmed milk, 3%; cod liver oil, 1%; dried yeast, 1%; NaCl, 1%.

The isotopically labelled compounds were fed overnight mixed with diet (10 g.), unless otherwise stated. In some cases sodium benzoate, *p*-aminobenzoic acid or γ -phenyl- α -aminobutyric acid were also fed in connexion with another investigation. After a time interval of between 1 and 5 days the animals were killed by exsanguination under anaesthesia. The details of the feeding experiments are given in Table 1.

Isolation of choline and creatine. After removal of the liver, the carcasses were minced and extracted with ethanol; choline was precipitated as the reineckate, converted to the chloroplatinate and degraded to trimethylamine chloroplatinate (du Vigneaud *et al.* 1941). In two experiments, creatinine was converted to creatine and isolated as the picrate of the potassium salt (du Vigneaud *et al.* 1941).

Synthesis of ^{14}C -choline and degradation of synthetic material. In order to check the assumption that the carbon atoms of trimethylamine originate only from the methyl groups of choline, the degradation was repeated on choline, labelled with ^{14}C in the hydroxyethyl group, which had been synthesized by the following series of reactions. It is probable that the last step, i.e. the condensation of 2-chloroethanol with trimethylamine, takes place via ethylene oxide, in which case the choline would contain radioactive isotope in both C

Table 1. Details of administration of isotopically labelled compounds

Details of animals					Details of labelled compound given					
Exp. no.	No. of rats	Sex	Aggregate body wt. (g.)	No. of days kept alive after feeding tracer	Compound fed	Wt. (mg.)	Radio-activity (μC)	Atom % excess	Specific radio-activity ($\mu\text{C}/\text{mmol.}$)	Quantity fed (mmol./100 g. body wt.)
1 (a)*	3	F	900	5	$\text{DL-}^{14}\text{CH}_2\text{OH} \cdot \text{CHNH}_2 \cdot \text{CO}_2\text{H}$	240.2	6.0	—	2.62	0.254
2 (b)	2	F	550	2.5	$\text{L-}^{14}\text{CH}_2\text{OH} \cdot \text{CHNH}_2 \cdot \text{CO}_2\text{H}$	122.0	10.0	—	8.60	0.211
3 (c)	2	F	508	2.5	$\text{D-}^{14}\text{CH}_2\text{OH} \cdot \text{CHNH}_2 \cdot \text{CO}_2\text{H}$	142.6	11.7	—	8.59	0.267
4 (d)	1	F	302	3	$^{14}\text{CH}_2\text{NH}_2 \cdot \text{CO}_2\text{H}$	9.6	9.6	—	75.07	0.0423
5	2	F	545	2	$^{14}\text{CH}_2\text{NH}_2 \cdot \text{CO}_2\text{H}^\dagger$	39.8	39.8	—	75.07	0.0973
6 (e)	1	F	260	1	$^{14}\text{CH}_3\text{OH}$	13.7	10.3	—	24.09	0.1645
					$\text{CH}_2^{15}\text{NH}_2 \cdot \text{CO}_2\text{H}$	10.0	—	30.2	—	0.0513
7 (f)	1	M	387	3	$\text{H}^{14}\text{CO}_2\text{Na}$	41.7	22.3	—	36.38	0.158
					$\text{CH}_2^{15}\text{NH}_2 \cdot \text{CO}_2\text{H}$	10.0	—	30.2	—	0.0345
8 (g)	2	F	590	4	$\text{CH}_2\text{NH}_2 \cdot ^{14}\text{CO}_2\text{H}$	45.6	20.5	—	15.61	0.223
					$\text{CH}_2^{15}\text{NH}_2 \cdot \text{CO}_2\text{H}$	53.0	—	30.2	—	—

* Substances added to diet:

(a) 200 mg. *p*-aminobenzoic acid, 200 mg. γ -phenyl- α -aminobutyric acid/animal (2 rats); 200 mg. sodium benzoate, 200 mg. γ -phenyl- α -aminobutyric acid/animal (1 rat).

(b) 100 mg. sodium benzoate, 100 mg. γ -phenyl- α -aminobutyric acid/animal.

(c) 200 mg. sodium benzoate, 200 mg. γ -phenyl- α -aminobutyric acid/animal.

(d) 200 mg. *p*-aminobenzoic acid, 200 mg. γ -phenyl- α -aminobutyric acid.

(e) 50 mg. sodium benzoate.

(f) 54 mg. sodium benzoate.

(g) 50 mg. sodium benzoate/animal; 50 mg. sodium benzoate/animal, 3 days later.

† By intraperitoneal injection.

atoms of the hydroxyethyl group, but this does not affect the conclusions drawn from the degradation experiment:

1941) afforded trimethylamine chloroplatinate which was completely non-radioactive.

${}^{14}\text{C}$ -Methyl-labelled sodium acetate (5.7 mg., 69.5 μC .) obtained from the Radiochemical Centre, Amersham) was diluted with non-radioactive acetic acid (2.60 g., 43.4 mmol.) and converted to chloroacetic acid (Ostwald, 1948). The crude product was refluxed with SOCl_2 (5 ml.) for 5 hr. and left at room temperature for 2 days (McMaster & Ahmann, 1928). Pure chloroacetyl chloride (6 g., 53.2 mmol.) was then added as carrier and the product was distilled using a Vigreux column (6 $\times$ 1 cm.), the fraction boiling at 100–106°/760 mm. Hg being collected. It was found impossible to remove all the SOCl_2 by fractional distillation, but the material was sufficiently pure for the next step. A solution of lithium aluminium hydride (2.75 g.) in dry ether (50 ml.) was added slowly with stirring to a cooled solution of the acid chloride in dry ether (50 ml.) (Sroog, Chih, Short & Woodburn, 1949). When the reaction was completed, dil. H_2SO_4 was added and the aqueous layer was extracted several times with ether. The ether extract was evaporated and the residue was distilled *in vacuo*, using a Vigreux column (6 $\times$ 1 cm.), the fraction b.p. 80–90°/15 mm. Hg being collected (yield, 1.71 g.). 2-Chloroethanol (1.39 g.) was treated with trimethylamine (2 ml.) in a sealed tube. After 48 hr. at room temperature the tube was heated at 90–100° for 4 hr. (Wurtz, 1868). The excess trimethylamine was then allowed to evaporate, the last traces being removed by heating the product at 215° in a high vacuum. Weight of residue was 2.3 g. A small portion of the choline chloride was converted to the chloroplatinate, m.p. 240–245° (decomp.). Radioactivity: 591 ± 13.7 counts/min./mg. sample, counted as an infinite thickness sample of 1.2 sq. cm. area. The calculated specific activity of the choline (free base) was 0.204 μC /mmol. Degradation of this synthetic material with alkaline permanganate (du Vigneaud *et al.*

Synthesis of labelled compounds used in feeding experiments

[β - ${}^{14}\text{C}$]-Serine. The synthesis of this compound has been described in a preliminary communication (Arnstein, 1949).

[α - ${}^{14}\text{C}$]-Glycine. [α - ${}^{14}\text{C}$]-Bromoacetic acid (supplied by the Radiochemical Centre, Amersham) was treated with excess NH_3 (sp.gr. 0.88), essentially as described by Olsen, Hemingway & Nier (1943).

[${}^{14}\text{COOH}$]-Glycine. ${}^{14}\text{C}$ -KCN (supplied by the Radiochemical Centre, Amersham) was reacted with *N*-chloromethylphthalimide (Sakami, Evans & Gurin, 1947). The product was hydrolysed with HCl and the glycine isolated from aqueous ethanolic solution by addition of pyridine.

Sodium [${}^{14}\text{C}$]-formate. Potassium [${}^{14}\text{C}$]-formate was prepared by hydrolysis of aqueous K^{14}CN at 250° for 2 hr. (Grant & Turner, 1950) and converted to sodium formate after vacuum distillation of the formic acid.

[${}^{14}\text{C}$]-Methanol. This was supplied by the Radiochemical Centre, Amersham; it was diluted about 40-fold before use to give material of a specific activity of about 25 μC /mmol.

RESULTS

The specific radioactivity of choline chloroplatinate, potassium creatine picrate and xanthidryl urea (when isolated) and the results of the degradation of choline to trimethylamine are given in Table 2. In order to compare different experiments the relative isotope coefficient (RIC) and the concentration coefficient (CC) were calculated (Table 3) as given by Anker (1948). The dilution factor is defined as the reciprocal of the concentration coefficient (CC) and gives the dilution of isotopic tracer which would

Table 2. Specific radioactivities and ${}^{15}\text{N}$ contents of isolated compounds

(The radioactivity was measured on a Geiger counter, using infinite thickness samples. The counting error is given as the standard deviation.)

Exp. no.	Labelled compound fed	Potassium creatine picrate	Xanthidryl urea	Choline chloroplatinate		Trimethylamine chloroplatinate
		$\mu\text{C} \times 10^{-6}/\text{mg.}$	$(\mu\text{C} \times 10^{-6} \text{ mg.})$	$\mu\text{C} \times 10^{-6} \text{ mg.}$	Atom % excess ${}^{15}\text{N}$	$(\mu\text{C} \times 10^{-6}/\text{mg.})$
1	$\text{DL-}^{14}\text{CH}_2\text{OH}\cdot\text{CHNH}_2\cdot\text{CO}_2\text{H}$	—	—	10.35 ± 0.2	—	1.68 ± 0.15
2	$\text{L-}^{14}\text{CH}_2\text{OH}\cdot\text{CHNH}_2\cdot\text{CO}_2\text{H}$	1.2 ± 0.6	12.5 ± 0.2	32.1 ± 0.5	—	7.85 ± 0.9
3	$\text{D-}^{14}\text{CH}_2\text{OH}\cdot\text{CHNH}_2\cdot\text{CO}_2\text{H}$	—	22.5 ± 1.5	Inactive	—	—
4	${}^{14}\text{CH}_2\text{NH}_2\cdot\text{CO}_2\text{H}$	—	14.45 ± 0.3	30.2 ± 1.3	—	6.47 ± 0.6
5	${}^{14}\text{CH}_2\text{NH}_2\cdot\text{CO}_2\text{H}$ (by intraperitoneal injection)	—	—	12.6 ± 0.6	—	0.67 ± 0.15
6	${}^{14}\text{CH}_3\text{OH}$	—	12.55 ± 1.3	45.0 ± 1.0	—	20.9 ± 1.0
	$\text{CH}_2^{15}\text{NH}_2\cdot\text{CO}_2\text{H}$	—	—	—	0.009	—
7	$\text{H}^{14}\text{CO}_2\text{Na}$	—	76.9 ± 1.8	73.5 ± 2.4	—	17.1 ± 0.8
	$\text{CH}_2^{15}\text{NH}_2\cdot\text{CO}_2\text{H}$	—	—	—	0.006	—
8	$\text{CH}_2\text{NH}_2\cdot{}^{14}\text{CO}_2\text{H}$	—	—	Inactive	—	—
	$\text{CH}_2^{15}\text{NH}_2\cdot\text{CO}_2\text{H}$	—	—	—	0.012	—

Table 3. *Dilution of isotopic tracer in choline and trimethylamine after feeding various labelled precursors*

(The relative isotope concentration (RIC) and concentration coefficient (CC) were calculated according to Anker (1948). The dilution factor is the reciprocal of the concentration coefficient. The percentage isotope in trimethylamine is given by the ratio $(\text{RIC}_{(\text{trimethylamine})}/\text{RIC}_{(\text{choline})}) \times 100$.)

Exp. no.	Compound fed	Choline		Trimethylamine		Isotope in trimethylamine (%)	Dilution factor	
		RIC ($\times 10^{-4}$)	CC ($\times 10^{-3}$)	RIC ($\times 10^{-5}$)	CC ($\times 10^{-4}$)		Choline	Trimethylamine
1	DL- $[\beta\text{-}^{14}\text{C}]$ -Serine	12.18	4.80	16.93	6.67	13.9	208	1449
2	L- $[\beta\text{-}^{14}\text{C}]$ -Serine	11.50	5.45	24.13	11.40	21.0	184	878
4	$[\alpha\text{-}^{14}\text{C}]$ -Glycine	1.24	2.93	2.27	5.36	18.2	341	1866
6	^{14}C -Methanol	5.75	3.50	22.92	13.90	39.8	286	719
	^{15}N -Glycine	2.98	5.81	—	—	—	172	—
7	Sodium ^{14}C -formate	6.23	3.93	12.41	7.84	19.9	254	1278
	^{15}N -Glycine	1.99	5.76	—	—	—	174	—
8	$^{14}\text{COOH}$ -Glycine	—	—	—	—	—	—	—
	^{15}N -Glycine	7.39	3.31	—	—	—	302	—

have been observed if exactly 1 mmol. of labelled compound had been fed per 100 g. body weight.

Methanol, sodium formate, glycine (labelled in the α -position or with ^{15}N) and L-serine (labelled in the β -position) were found to be precursors of choline. The dilution of tracer was somewhat lower with L-serine than with the other compounds. Degradation of the choline showed that methanol was converted to choline methyl groups with greater efficiency than were the α -carbon atom of glycine, the β -carbon atom of L-serine or sodium formate. After administration of $^{14}\text{COOH}$ -glycine or D- $[\beta\text{-}^{14}\text{C}]$ -serine the choline was completely non-radioactive. ^{15}N -Glycine, fed at the same time as the carboxyl-labelled compound, was incorporated into choline to about the same extent as α -labelled glycine.

Recently, other workers have also shown that methanol (du Vigneaud & Verly, 1950) and formate (Welch & Sakami, 1950; Sakami, 1950) are converted to choline methyl groups, though full experimental details have not yet been published.

DISCUSSION

The nutritional interrelationships of choline and methionine have been satisfactorily explained by the ability of these substances to act as donors of labile methyl groups (for a summary dealing with the transfer of methyl groups in the body see du Vigneaud, 1948). Only a few other compounds such as betaine and dimethylthetin (du Vigneaud, Moyer & Chandler, 1948) have been found to supply labile methyl groups and thus to replace choline or methionine in nutrition. On the other hand, dimethylaminoethanol, though a precursor of choline and resembling it in preventing fatty livers and haemorrhagic kidneys in rats (du Vigneaud, Chandler, Simmonds, Moyer & Cohn, 1946), is not available for growth purposes, presumably because its methyl groups are not metabolically labile.

Although *in vivo* synthesis of choline takes place, the animal would appear to be unable to synthesize methyl groups at a rate sufficient for optimal growth. Alternatively, the rat may synthesize dimethylaminoethanol, but conversion of this compound to choline may require a preformed labile methyl group.

Hitherto there has been little experimental evidence to indicate whether biosynthesis of methyl groups occurs in the rat or whether all the methyl groups are derived from the diet. When the body water of the white rat, kept on a diet adequate in labile methyl groups, was enriched with heavy water, some deuterium was incorporated into the methyl groups of choline (du Vigneaud, Simmonds, Chandler & Cohn, 1945). Although this isotope might have been introduced into the methyl groups by an exchange of hydrogen atoms, e.g. by an oxidation-reduction mechanism, it was thought more likely that the white rat synthesized a small, but significant amount of methyl groups, even though preformed labile methyl groups were provided in the diet.

The present experiments show unequivocally that, on a stock diet containing an adequate amount of labile methyl groups, the white rat synthesized choline methyl groups from one-carbon precursors which can be derived from the α -carbon atom of glycine or the β -carbon atom of L-serine as well as from formate or methanol. D- $[\beta\text{-}^{14}\text{C}]$ -Serine and $^{14}\text{COOH}$ -glycine were not converted to choline. Since both these compounds are oxidized to carbon dioxide it is evident that the intact animal is unable to reduce carbon dioxide to methyl groups to any significant extent.

Earlier work with ^{15}N had shown that both ethanalamine and glycine are precursors of choline (Stetten, 1941), but it was not known whether ethanalamine arises by reduction of glycine, as suggested by Shemin (1946), or by decarboxylation of serine

(Stetten, 1942). Since glycine and serine are in dynamic equilibrium as shown by experiments with ^{15}N (Elliott & Neuberger, 1950), the mechanism of ethanolamine formation from these compounds can

possible that the precursor is a phosphorylated one-carbon compound derived from the β -carbon atom of serine during its conversion to glycine, thus: (*C = the labelled C atom)

be better elucidated with isotopic carbon than with ^{15}N . L-[β - ^{14}C]-Serine was found to be converted to choline with about the same efficiency as [^{15}N]-glycine, but [$^{14}\text{COOH}$]-glycine, as already mentioned, was not a precursor of choline. Since [$^{14}\text{COOH}$]-glycine is converted to serine containing tracer in the carboxyl group only (Sakami, 1948; Siekevitz *et al.* 1949), these experiments show that the ethanolamine moiety of choline, and hence presumably ethanolamine itself, is derived from serine with loss of the carboxyl group. In this connexion it is of interest that D-[β - ^{14}C]-serine is not a precursor of either the ethanolamine moiety of choline or the methyl groups. This difference between D- and L-serine is one more illustration of metabolic differences between stereoisomers. Since L- but not D-serine is converted to glycine (Shemin, 1946), it may be presumed that the D-isomer does not split off the β -carbon atom as a one-carbon fragment and hence is not a precursor of methyl groups. On the other hand, both isomers are converted to acetate with about equal efficiency (Arnstein, 1950b).

The identity of the one-carbon methyl-group precursor is at present unknown. Although both formaldehyde and formate are degradation products of the β -carbon atom of L-serine and of the α -carbon atom of glycine (Siekevitz & Greenberg, 1950), these compounds may not be involved as such. It is

According to this view, formate and the α -carbon atom of glycine would be converted to this one-carbon precursor via the β -carbon atom of serine (Sakami, 1948, 1949b), accounting for the greater dilution of isotopic tracer in the choline methyl groups after feeding these compounds (Table 3) compared with L-serine. The relatively efficient conversion of methanol to choline methyl groups can be explained by assuming its conversion to a precursor (II) which is metabolically closer to methyl groups than that derived from formate. By contrast, methanol and formate are converted to the ethanolamine moiety of choline with about equal efficiency, suggesting that both the compounds give rise to intermediates which condense with glycine to give serine and thence ethanolamine.

Since α -labelled glycine gives rise to serine containing approximately equal amounts of isotope in the α - and β -position (Sakami, 1949b), the ethanolamine derived from this precursor will be labelled in both carbon atoms. With the other compounds fed only the β -carbon atom of serine and hence only one carbon atom of ethanolamine will contain isotope. Allowing for this difference, the radioactivity per carbon atom in the methyl groups and in the ethanolamine moiety, obtained in the various experiments, has been calculated (Table 4). If the amount of labile methyl groups in the diet and their turnover

Table 4. Calculated radioactivity of the methyl groups and ethanolamine moiety of choline derived from fed precursors

Exp. no.	Compound fed	Specific radioactivity ($\mu\text{c./g.mol.}$)			Maximum no. of carbon atoms of choline which can be derived from labelled atom of precursor fed		Radioactivity/g.mol./C atom derived from precursor		Ratio (b)/(a)
		Choline	Trimethyl- amine	Ethanol- amine moiety	Methyl groups	Ethanol- amine moiety	Methyl group (a)	Ethanol- amine moiety (b)	
1	DL- $[\beta\text{-}^{14}\text{C}]$ -Serine	3.19	0.444	2.75	3	1	0.148	2.75	18.6
2	L- $[\beta\text{-}^{14}\text{C}]$ -Serine	9.89	2.08	7.81	3	1	0.693	7.81	11.4
4	$[\alpha\text{-}^{14}\text{C}]$ -Glycine	9.31	1.70	7.61	3	2	0.567	3.81	6.7
6	^{14}C -Methanol	13.86	5.52	8.34	3	1	1.84	8.34	4.5
7	Sodium ^{14}C -formate	22.66	4.51	18.15	3	1	1.50	18.15	12.1

rate were known, the number of methyl groups synthesized from the fed precursors per molecule of choline could be calculated. As these factors were not ascertained no quantitative deductions are possible. It is of interest however that, compared with the ethanolamine formed, only a small number of methyl groups appear to have been synthesized by the animal from the fed precursors. It is possible that this apparently slow rate of methyl group synthesis is due mainly to the adequate supply of labile methyl groups in the diet.

SUMMARY

1. The biosynthesis of choline has been studied by feeding D- and L- $[\beta\text{-}^{14}\text{C}]$ -serine, $[\alpha\text{-}^{14}\text{C}]$ -glycine, $[\text{C}^{14}\text{COOH}]$ -glycine, $[\text{C}^{14}]$ -methanol and $[\text{C}^{14}]$ -formate to adult rats.

2. It is concluded that L-serine is converted to the

ethanolamine moiety of choline by loss of the carboxyl group. D-Serine is not a precursor of choline.

3. Methanol, formate, the β -carbon atom of L-serine and the α -carbon atom (but not the carboxyl carbon atom) of glycine are precursors of choline methyl groups.

4. Carbon dioxide, arising by *in vivo* oxidation of D- $[\beta\text{-}^{14}\text{C}]$ -serine or $[\text{C}^{14}\text{COOH}]$ -glycine, is not converted to choline methyl groups.

5. The rate of synthesis of choline methyl groups from the above precursors appears to be slow compared with that of the ethanolamine moiety.

6. A synthesis of choline labelled with ^{14}C in the ethanolamine moiety is described.

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