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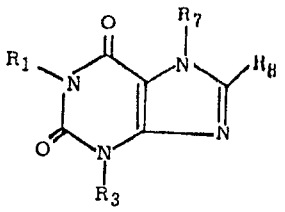
(54) **Xanthine tracers and their preparation**

(57) Compounds useful as tracers in the radioimmunoassay of xanthine derivatives such as theophylline and pharmacologically related drugs have the formula



Wherein at least one R_1, R_3, R_7 or R_8 is a radioiodinated radical and wherein, if not substituted by a radioiodinated radical, the remaining R_1, R_3, R_7 or R_8 groups are otherwise identical to the substituents at these positions in the xanthine derivative to be assayed. Ordinarily, R_1 is hydrogen, acetate or methyl; R_3 is methyl; R_7 is hydrogen, acetate or methyl; and R_8 is hydrogen. The tracers are made by linking radioiodinatable or preradioiodinated radicals to the xanthine derivative which is to be assayed. The tracers may be employed in known radioimmunoassay techniques.

Certain of the chemical formula(e) appearing in the printed specification were submitted in formal form after the date of filing.

GB 2 028 312 A

SPECIFICATION

Xanthine tracers and their preparation

This invention relates to the radioimmunoassay of xanthine derivatives, including methods of radioimmunoassay compounds therefor and methods of preparation of the compounds.

A number of xanthine derivatives exhibit biological activity. These derivatives are generally 1, 3 or 7 lower alkyl-substituted, and their activity varies depending upon which of these positions of the xanthine nucleus are alkylated. For example, theophylline, theobromine and caffeine differ from one another solely by the location of methyl groups at these three sites.

Theophylline is a particularly important biologically active xanthine derivative (1,3-dimethylxanthine). Theophylline is a bronchodilator which can be useful in the treatment of asthma. The importance of monitoring theophylline levels is illustrated by the finding of widely varying serum theophylline concentrations in patients receiving identical doses. Since theophylline is metabolized in the liver, factors which affect the liver may affect theophylline metabolism resulting in modified serum half-lifes. Factors such as cigarette smoking, chronic theophylline therapy, alcoholism, barbiturates, allopurinol, and impaired hepatic or renal function may lead to toxic or inadequate dosing. Differences in serum levels between individuals may arise from the drug form used (tablet, suppository, elixir), site administration (oral, rectal), and rate and quantity of theophylline absorbed. This is in part a result of the low solubility of theophylline in the gastrointestinal environment.

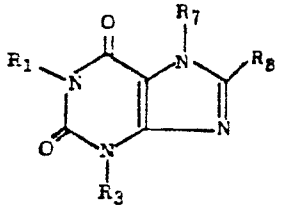
Titering of serum theophylline levels is particularly important in infant care because premature infants have a greater sensitivity to adverse side effects of high theophylline levels and because the serum half-life of theophylline in premature infants is longer and more variable than in adults or older children.

Gas liquid chromatography, high pressure liquid chromatography and spectrophotometry have been used to determine concentrations of theophylline and other xanthine derivatives. These techniques tend to be more labor intensive and less rapid for multisample batch sizes than radioimmunoassay methods.

Radioimmunoassay requires smaller sample sizes than the above methods. This is an advantage for titering theophylline levels in premature infants. However, prior radioimmunoassay methods for theophylline have employed tritiated theophylline as tracer. This has necessitated the use of scintillation counting of tritium, a considerably less convenient technique than gamma counting of iodine isotopes. Tritium labeled tracers also have a lower specific activity than iodinated tracers, thus limiting the sensitivity of the radioimmunoassay. Finally, tritium may have a tendency to exchange with hydrogen ions in solution depending upon the substitution site.

It is one object of this invention to provide new xanthine derivatives which are useful in the preparation of tracers for the radioimmunoassay of theophylline and related compounds.

The present invention provides a compound useful in the immunoassay of a given xanthine derivative, the compound having the following formula:



Wherein at least one R_1, R_3, R_7 or R_8 is a radioiodinated radical and wherein, if not substituted by a radioiodinated radical, the remaining R_1, R_3, R_7 or R_8 groups are otherwise identical to the substituents at these positions in the given xanthine derivative to be assayed. Ordinarily, if not substituted with a radioiodinated radical, R_1 is hydrogen, acetate or methyl; R_3 is methyl; R_7 is hydrogen, acetate or methyl; and R_8 is hydrogen.

Any one or more of R_1, R_3, R_7 or R_8 may be selected as the point of substitution of the radioiodinated radical, depending upon the xanthine derivative to be assayed. As a general rule the radioiodinated radical should be substituted at a point on the xanthine ring which is as distant as possible from the portions of the ring which distinguish the xanthine derivatives to be detected and discriminated. Thus it is unusual for more than two of the above four positions to be substituted with radioiodinated radicals.

The structure of the radioiodinated radical is not critical; its purpose is merely to link a radioisotope of iodine such as ^{125}I or ^{131}I to the xanthine moiety. However, it should be neither so large as to adversely affect binding of the tracer to antibody nor capable of reacting adversely with radioimmunoassay reagents or samples.

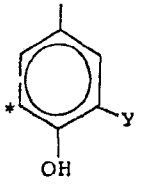
The radical will generally fall within the class of unsaturated rings, usually heterocycles but also hydroxyl-substituted, unsaturated cyclic hydrocarbons, and aliphatic radicals. The aliphatic radicals may be branched or normal, saturated or unsaturated. Ordinarily, the aliphatic radicals will be normal hydrocarbons containing from 1 to about 10 carbon atoms and having at least one double bond. Xanthine derivatives

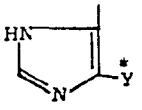
having haloalkyl substituents, including iodoalkyl groups, are well known. Such derivatives may be employed as tracers in this invention by following the prior art syntheses but with the replacement of radioiodine for nonisotopic iodine. While radioiodinated aliphatic radicals are useful it is preferred to employ radioiodinated rings, particularly unsaturated heterocycles. Radioiodinated alkenyls are preferred over radioiodinated alkyls.

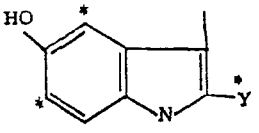
Ordinarily the radioiodinated radical will be the group $L(Z)_n$, wherein L is a linking group, Z is a radioiodinated ring and n ranges from 1 to about 10. However, it is also contemplated that tracers of this invention will contain no linking group but instead a direct bond between the radioiodinated ring and the xanthine moiety. Under certain circumstances both the linking group and the ring will be radioiodinated. The total molecular weight of the $L(Z)_n$ moiety ordinarily will not exceed 2000 and is generally less than 1000.

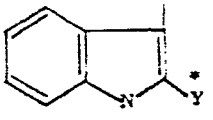
The linking group is ordinarily a product of the process used for binding a radioiodinatable or preradioiodinated ring to the xanthine moeity. It is preferably a hydrocarbon, or several hydrocarbon radicals joined by ester, ether, or amide groups. The hydrocarbon groups may in turn be substituted with halo, hydroxy, keto, carboxy, alkoxy, alkoxycarbonyl, alkylamino or amino groups. Representative linking groups are the cyclic, normal or branched alkylenes or alkenylenes, such as alkylenes and alkenylenes substituted with hydroxy, keto, carboxy or amino groups; esters; ethers; carboxyl or phosphoryl esters; amines and amides.

The rings employed in the radioiodinated radicals are generally phenol, imidazole or indole radicals having the following structures.









Wherein Y is hydrogen, halo or lower alkyl up to about 7 carbon atoms. These radicals may then be radiolabeled, preferably radioiodinated with one radioiodine atom at the positions of labeling indicated with an asterisk. The radicals may be radioiodinated at the Y position where Y is hydrogen prior to radioiodination. Other rings such as pyrrole, furan or thiophene may also be employed. The use of these rings as opposed to an aliphatic or branched chain radioiodinated radical is favored because of the generally greater stability of iodination. However, this advantage may in some cases be offset by the bulkiness of the ring and its consequent effect on antibody binding.

Also included within the scope of this invention are xanthine derivatives which are capable of radioiodination in the synthesis of the novel tracers herein. When a ring or substituent is said to be radioiodinatable or capable of radioiodination it is meant that iodine may be added to or otherwise incorporated into that ring or substituent without iodination of the xanthine ring, such as by the radioiodination methods disclosed herein. These tracer precursors are generally conjugates of xanthine and at least one of the radioiodinatable rings described above in which the rings are linked to at least one of the xanthine 1, 3, 7 or 8 positions, although alkanols and alkenyls, particularly polyalkenyls, may be conjugated to the xanthine nucleus at one or more of the 1, 3, 7 or 8 positions.

The tracers of this invention have broad use in any radioimmunoassay technique wherein a sample is

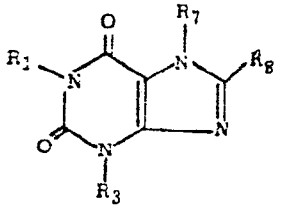
contacted with a constant amount of tracer and an antibody which will selectively bind the sample xanthine and the tracer, followed by measuring the degree of binding of the tracer to the antibody. The tracers of this invention may be used with any of the various techniques for radioimmunoassay which employ a tracer for the substance tested, including primarily the competitive and saturation methods. The compounds to which such radioimmunoassays are directed do not need to be drugs but can be biologically inactive intermediates used in the production of the drugs or found as *in vivo* metabolites. Caffeine in biological fluids or in consumer goods may also be measured by such methods.

A novel method of synthesizing these tracers comprises forming an 8-alkanoic acid of xanthine by condensing a diamino pyrimidinedione with a cyclic anhydride, followed by formation of an amide bond between the xanthinealkanoic acid and an amino-substituted radioiodinatable or radioiodinated ring using alkyl chloroformate activation of the alkanoic acid. Alternatively, an 8-aminoalkyl xanthine derivative may be reacted in the same fashion with an activated carboxyl-substituted radioiodinatable or radioiodinated ring. Here, however, unless a protective group is present on the 7 position nitrogen it is likely that both 7 and 8 substitution will occur, thereby necessitating conventional isolation procedures if a mono-substituted tracer is desired.

The particular amino-substituted rings are ordinarily selected from the aminoalkyl, aminoalkanol or aminoalkanoic acid derivatives of radioiodinatable rings such as indole, phenol or imidazole. Suitable amino derivatives are tyrosine, histidine, histamine, 4-hydroxyphenylglycine or tyrosinol. However, amino-terminated polypeptide radicals containing at least one of the aforesaid radioiodinatable rings may also be employed, although polypeptides containing more than about 10 amino acid residues are not desirable. Polypeptides above this size may adversely affect antibody binding, and they may be unstable in storage. The polypeptide substituents used in the tracers of this invention should exhibit neither antigenic nor enzymatic activity.

In the final step of this method the radioiodinatable ring is radioiodinated with ^{125}I or ^{131}I by known techniques such as those described *infra*. This step will of course be redundant if the ring has been radioiodinated prior to condensation with the xanthine ring.

Certain radioiodinatable xanthine derivatives within the scope of this invention are novel. These derivatives comprise compounds having the formula:



Wherein

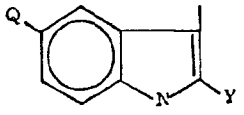
(a) R_1 is an imidazole, pyrrole, thiophene, indole or polyunsaturated alkenyl radical;

(b) R_3 is a nonenzymatic radioiodinatable radical, in particular an unsaturated heterocyclic radical or a hydroxy-substituted, unsaturated cyclic hydrocarbon radical;

(c) R_7 is a pyrrole, furan, thiophene, polyunsaturated alkenyl, imidazole or indole radical, with the proviso that

(1) the imidazole radical has the structure $-L(X)_n$ wherein L is a linking group containing at least one ester, ether, amide or amino bond, X is imidazole and n ranges from 1 to about 10; and

(2) the indole radical has the structure:



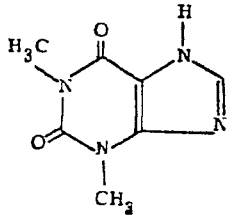
wherein Q is hydrogen or hydroxyl and Y is hydrogen, halo or lower alkyl up to about 7 carbon atoms; and

(d) R_8 is a pyrrole, furan or imidazole radical wherein the imidazole radical is set forth in part (c) (1); with the proviso that no more than two of R_1, R_3, R_7 or R_8 are the above radicals and that if R_1, R_3, R_7 or R_8 are not one of the above radicals then R_1 is hydrogen, acetate or methyl; R_3 is methyl; R_7 is hydrogen, acetate or methyl; and R_8 is hydrogen.

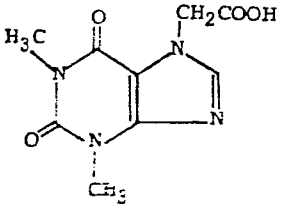
Description of the Preferred Embodiments

The following is a tabulation of the predominant, pharmacologically active xanthine derivatives to which the radioimmunoassays of the invention may be directed using the novel tracers of this invention.

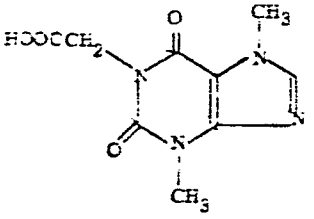
Theophylline



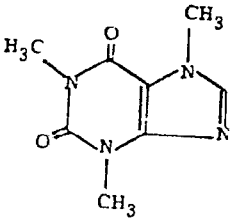
7-Theophyllineacetic Acid



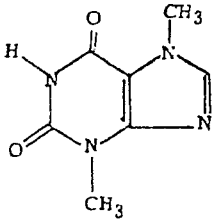
1-Theobromineacetic Acid



Caffeine



Theobromine



Substituents R_1, R_3, R_7 and R_8, when not representing a radioiodinated radical, are relevant only insofar as they represent the same substituents found in the xanthine to which the assay is directed. The xanthine tracer should vary as little as possible from the target xanthine so as to successfully mimic the binding of target to its antibody. Thus, for example, a tracer suitable for use in the radioimmunoassay of theophylline will have R_1 and R_3 substituted with methyl, R_7 with hydrogen and R_8 with a radioiodinated radical. Alternatively, R_3 may be substituted with a radioiodinated radical in place of methyl.

Theobromine tracers will also be R_3 or R_8, or both R_3 and R_8 substituted. Here, however, R_1 will be hydrogen rather than methyl because this feature distinguishes theobromine from theophylline.

Caffeine tracers should only be 8-substituted because the presence of methyl at the R_7 position distinguishes caffeine from theophylline. Of course, if theophylline is not expected to be present in the

sample or can be removed then 1,3-dimethylxanthine radioiodinated at the R_7 position may be employed. Generally, tracers having the radioiodinated radical at the R_7 position are least desired while R_3 and, particularly, R_8 are preferred. Cross reactivity is not a bar to use of a tracer in an asay where the interference from the cross reactive substance may be discounted at the desired level of accuracy, where the substance ordinarily will be present in insignificant or known amounts, or where it may be removed by adsorption and the like.

The structure of the relevant portions of the xanthine derivative to be assayed generally will be known at the time the tracer is prepared, as will the presence or absence of potentially interfering, related xanthine derivatives, so the skilled artisan will be able to readily select the appropriate site or sites for substitution of radioiodinated radicals. In fact, the starting material for synthesis of the tracers may be the xanthine derivative itself. Thus in this case it would not even be necessary to know the structure of the xanthine for which one is testing.

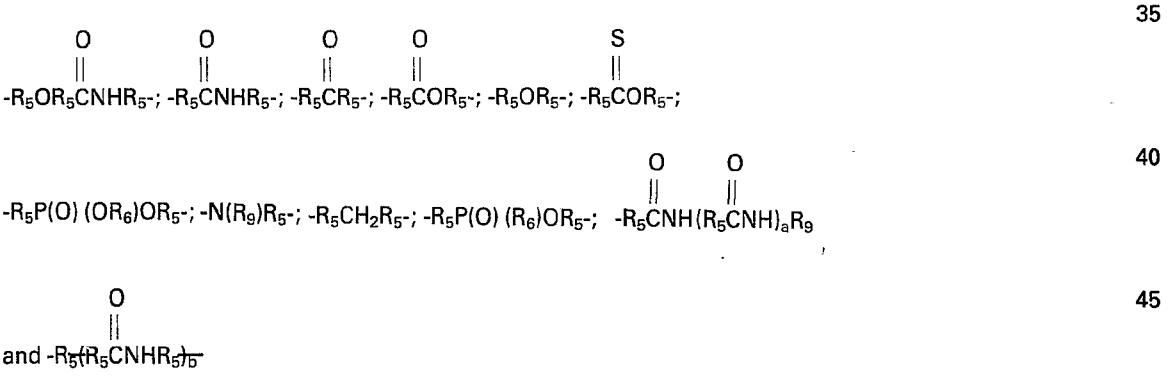
The radioiodinated radical may be aliphatic, cyclic or both combined. Where the radical is aliphatic it will contain from 1 to about 10 carbon atoms. It is preferred to employ from 3 to 6 carbon atoms in a normal rather than branched configuration with the radioiodine substituted as distant as possible from the xanthine nucleus. It is also preferred that the aliphatic radical be alkenyl. In such a case it is most desirable that radioiodine be substituted at or α to a double bond. The aliphatic radicals are also preferably substituted with groups which will increase their solubility, particularly hydroxyl, amino, carboxyl and keto. However, other substituents such as alkoxy, halo, alkoxy-carbonyl or alkylamino groups may also be present.

Also within the scope of this invention are tracers wherein the 8 position of the xanthine ring is directly substituted with an atom of radioiodide. 8-iodotheophylline, for example, is well-known and may be synthesized using ^{125}I to yield tracers suitable for use according to this invention.

Ordinarily the radioiodinated radicals of this invention will be radioiodinated rings which are bonded to the xanthine nucleus directly or, preferably, through a linking group. The rings are preferably unsaturated carbocycles having a ring hydroxyl substituent or unsaturated heterocycles. Exemplary of the latter are imidazole, indole, pyrrole, furan and thiophene, with imidazole being preferred. Phenol is an example of the former. 6-hydroxyindole is a hybrid of both types of rings. These rings should be bonded through the ring carbon atoms to the xanthine nucleus or the linking group at a position as distant as possible from the ring hydroxyl group or non-carbon atoms.

Where a linking group is employed the radioiodinated radical will have the structure $L(Z)_n$ as described generally above. The number of Z rings, n, is usually one or two, with one being preferred, but if a high tracer specific activity is desired then n may be greater than 2.

L is a bond or is generally selected from one of the radicals:



$-R_5OR_5\overset{O}{\overset{\|}{C}}NHR_5-$; $-R_5\overset{O}{\overset{\|}{C}}NHR_5-$; $-R_5CR_5-$; $-R_5\overset{O}{\overset{\|}{C}}OR_5-$; $-R_5OR_5-$; $-R_5\overset{S}{\overset{\|}{C}}OR_5-$;

$-R_5P(O)(OR_6)OR_5-$; $-N(R_9)R_5-$; $-R_5CH_2R_5-$; $-R_5P(O)(R_6)OR_5-$; $-R_5\overset{O}{\overset{\|}{C}}NH(R_5\overset{O}{\overset{\|}{C}}NH)_aR_9$

and $-R_5\overset{O}{\overset{\|}{C}}(R_5CNHR_5)_{75}-$

wherein

(i) R_5 is a bond; a substituted or unsubstituted hydrocarbon, ordinarily a cyclic, normal or branched alkylene or alkenylene; or such alkylene or alkenylene substituted with halo, hydroxy, keto, carboxy, alkoxy, alkoxycarbonyl, amino or alkylamino groups;

(ii) R_6 is alkyl of from 1 to about 6 carbon atoms;

(iii) R_9 is hydrogen or a substituted or unsubstituted hydrocarbon, ordinarily a cyclic normal or branched alkylene or alkenylene; or such alkylene or alkenylene substituted with halo, hydroxy, keto, carboxy, alkoxy, alkoxycarbonyl, amino or alkyl-amino groups;

(iv) a ranges from 1 to about 10; and

(v) b is 2 or 3.

The structures $-R_5\overset{O}{\overset{\|}{C}}NHR_5-$, $-R_5CH_2R_5-$, $-R_5OR_5\overset{O}{\overset{\|}{C}}NHR_5-$, $-R_5CR_5-$, $-R_5OR_5-$, $-N(R_7)R_5-$

and -R_5(-R_5CNHR_5-)$_b$ are most desirable, with -R_5CNHR_5- being preferred.

R_5 and R_9 may represent the same or different alkylene or alkenylene groups. These groups should generally contain from 1 to about 10 carbon atoms. Fully saturated, straight or branched chain hydrocarbons of from 1 to about 5 carbon atoms are preferred. They ordinarily will contain no more than two halo, hydroxy, keto, carboxy, alkoxycarbonyl, amino or alkylamino substituents. The keto, hydroxy, carboxy or amino substituents are preferred. Halogen substituents may include bromine, chlorine or nonradioactive iodine. The alkoxy, alkylamino or alkoxycarbonyl groups will generally contain normal hydrocarbons of from 1 to about 3 carbon atoms.

Representative cyclic R_5 or R_9 groups are cyclohexyl, cyclopentyl, and phenyl, but here as in aliphatic hydrocarbons it is desirable to substitute the carbon atoms with radicals such as keto, hydroxy, carboxy or amino to increase the solubility of the tracers or their precursors. Other substituents which may be employed with cyclic R_5 or R_9 radicals include halogen such as bromine, chlorine or nonradioactive iodine, and alkoxy, alkylamino or alkoxy-carbonyl where the alkyl is a normal or branched hydrocarbon of from 1 to about 3 carbon atoms.

Examples of aliphatic R_5 are ethylene, methylene, 2-hydroxy propylene, 3-hydroxypropylene, 3-ethyl-2-pentynylene, isopropylene, butylene, isobutylene, 3-aminoisobutylene, 3-dimethylaminoisobutylene, 2-hydroxyisobutylene, heptylene, 2-aminoheptylene, hexylene, 2-ethylheptylene, 2-hydroxy-heptylene, 1-carboxyethylene, 3-carboxymethyl hexylene, 3-methoxyheptylene and 1-hydroxymethylethylene. It is most preferred that R_5 be an unsubstituted, normal alkylene of 3 to 5 carbon atoms, for example butylene. Suitable R_9 groups include all of the foregoing for R_5 except that the groups will be monovalent, for example ethyl or isobutyl.

In the novel radioiodinatable xanthine derivatives or tracer precursors described above, R_1 is preferably an imidazole radical. R_3 is preferably an unsaturated heterocyclic radical such as imidazole, although a phenol radical is also satisfactory. If R_3 is a polypeptide containing such a radical then the polypeptide should be neither antigenic nor enzymatic.

R_7 is preferably an imidazole-containing radical as well, although in the case of this position the imidazole ring should be linked to the xanthine nucleus by a linking group which includes an ester, ether, amide or amino bond.

Suitable linking groups are:-

-R_5OR_5CNHR_5-; -R_5CNHR_5-; -R_5COR_5-; -R_5OR_5-; -R_5P(O)(OR_6)OR_5-;

-R_5CNH-(-R_5CNH-)$_a$$R_9$; -N($R_9$)$R_5$-; R_5-(-R_5CNHR_5-)$_b$; or -R_5CNH-(-R_5CNH-)$_a$$R_9$,

wherein R_5, a, b and R_9 are defined above.

The group -R_5CNHR_5- is preferred.

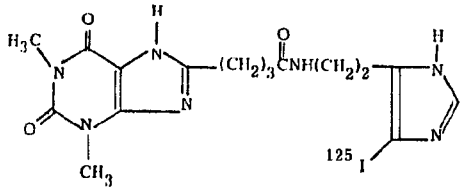
R_8 is preferably an imidazole radical as defined above.

Unless otherwise specified, the radioiodinatable rings set forth above may be directly bonded to the xanthine nucleus or linked by way of a linking group L which may be solely a carbon chain without any intervening ester, ether, amide or amino bond as is the case with R_7. The polyunsaturated alkenyl substituents found at R_1, R_3 or R_7 are preferably conjugated dienes having from 5 to 10 carbon atoms, most preferably pentadienyl.

The following table includes representative tracers within the scope of this invention. The tracer precursor compounds will be identical to those in this table except that hydrogen is present instead of ^{125}I or ^{131}I. The first compound is the preferred tracer.

TABLE
Xanthine Tracers

1.



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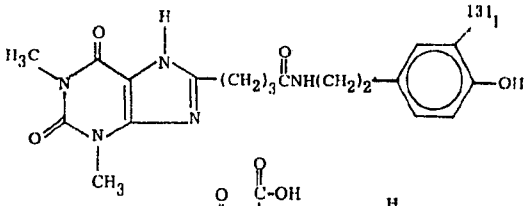

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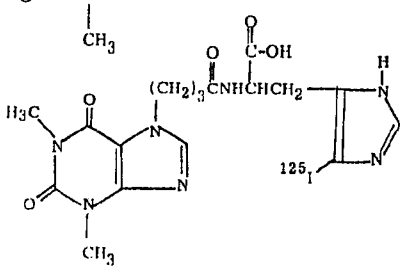

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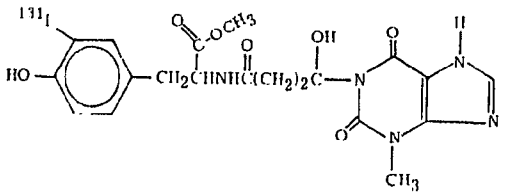

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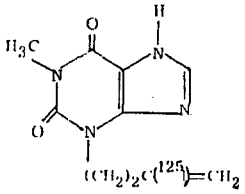

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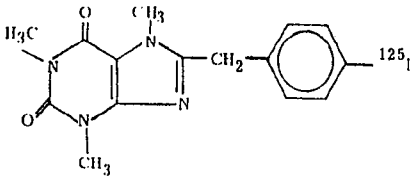

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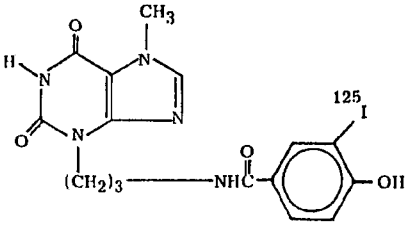
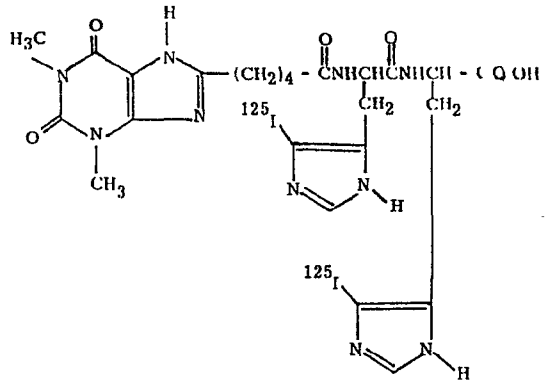
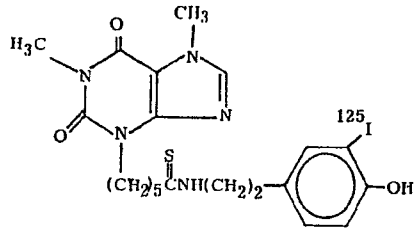
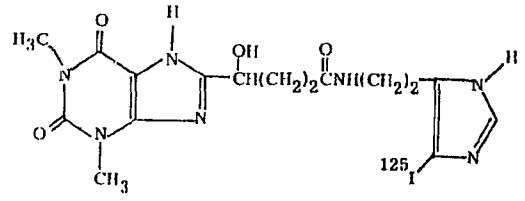
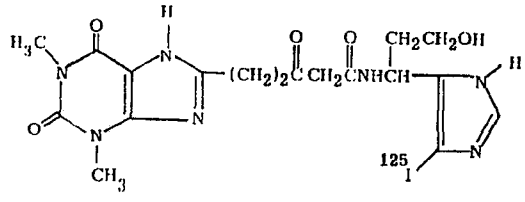
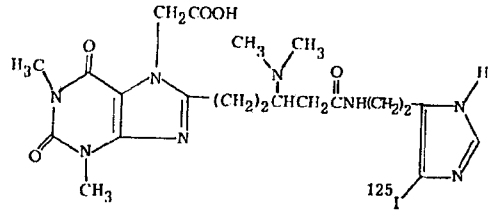


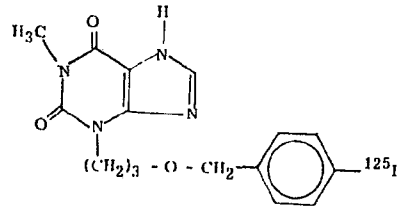
8. 

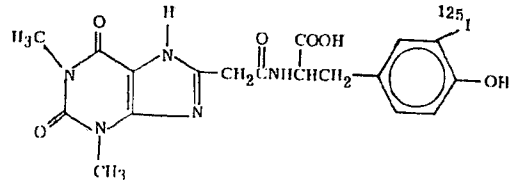
9. 

10. 

11. 

12. 

13. 

14. 

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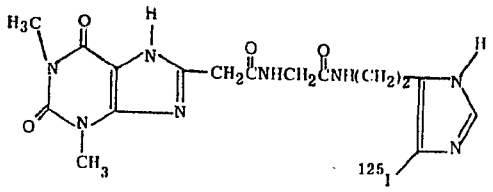

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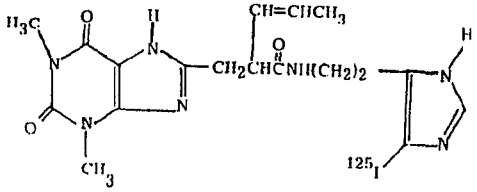

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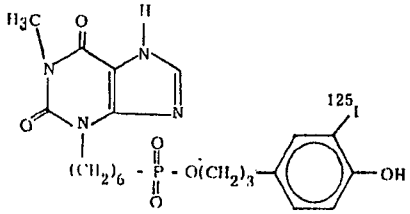

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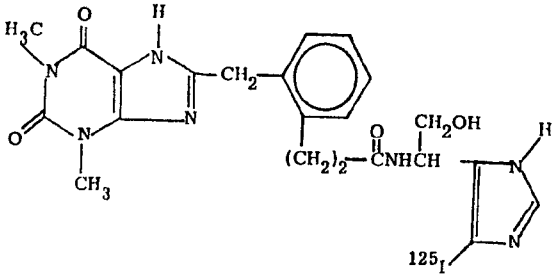

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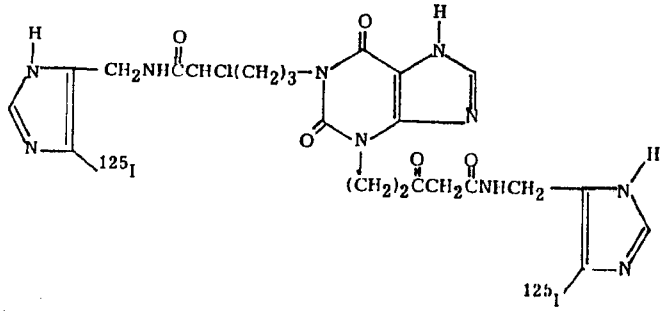

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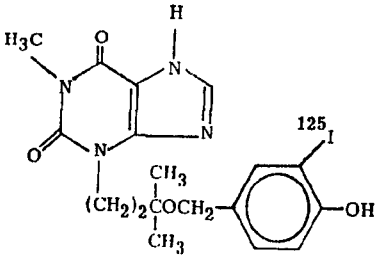

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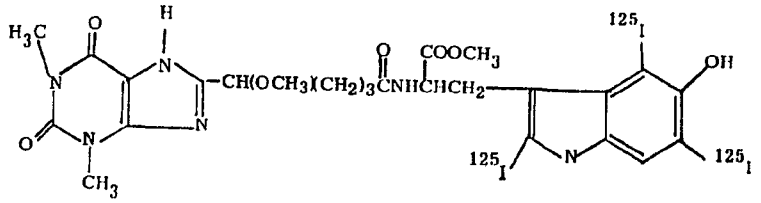
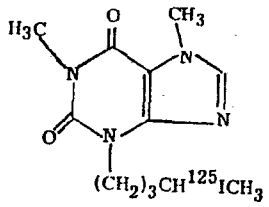
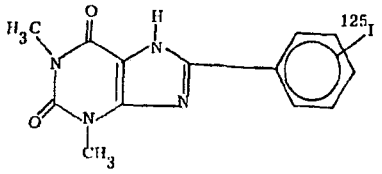
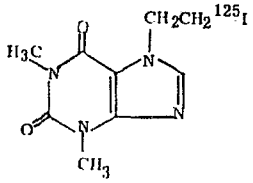


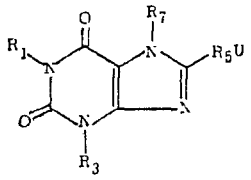
22. 

23. 

24. 

Representative tracers of this invention for radioimmunoassay of xanthine derivatives may be prepared by

(a) providing a starting compound having the structure



wherein

(i) R_5 is a bond; a cyclic, normal or branched chain alkylene or alkenylene; or such alkylene or alkenylene substituted with halo, hydroxy, keto, alkoxy, alkoxycarbonyl, carboxyl, amino or alkylamino groups;

(ii) U is carboxyl or amino; and

(iii) R_1, R_3 and R_7 are identical to the substituents at these positions in the xanthine derivative to be radioimmunoassayed;

(b) providing a radioiodinatable or radioiodinated compound having a carboxyl substituent if U is amino or an amino substituent if U is carboxyl;

(c) forming a mixed anhydride by reacting the carboxyl substituent with an activating agent; and

(d) reacting the mixed anhydride with the amino substituent to form a peptide bond between the radioiodinatable or radioiodinated compound and the starting compound.

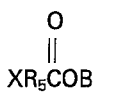
The starting compound described above may be prepared by synthesizing 8-(carboxyalkyl)-1,3-dimethylxanthine following the method of Cook et al, "Research Communications in Chemical Pathology and Pharmacology" *13*(3):497-505 (1976). The carboxyalkyl moiety of this compound may be supplied with the various R_5 substituents discussed above by employing a cyclic anhydride containing those substituents. The length of the anhydride carbon chain will be proportional to the length of the carboxyalkyl moiety.

The carboxyl derivative is then coupled to an amino-substituted radioiodinatable ring-containing compound, an amino-substituted radioiodinatable aliphatic group or an amino-substituted preradioiodinated compound by generation of mixed anhydrides using an activating agent such as ethyl chloroformate, isobutyl chlorformate of pivaloyl chloride in a conventional anhydrous aprotic solvent at low temperature (0° - 10°C). N,N-dimethyl formamide is the preferred solvent and one equivalent of organic base such as triethylamine is added to consume hydrochloric acid generated in the mixed anhydride formation. The amino compound to be coupled to the mixed anhydride is added to the reaction mixture in either aqueous solution or a mixed organic solvent; the reaction of the amino compound with the anhydride is apparently more rapid than hydrolysis of the anhydride.

Isolation of the desired compound may be accomplished by chromatography on an anion exchange resin, which is preferable, or by other known techniques such as thin layer chromatography on silica gel.

The tracers of this invention in which the xanthine 1, 3, or 7 positions are substituted with radioiodinated or radioiodinatable radicals, *i.e.* which are N-substituted, may be prepared by first forming an alkali metal, *e.g.*, potassium or sodium, salt of the xanthine derivative to which the assay is to be directed. This salt is then reacted with a lower alkyl ester of an ω-halogenated normal or branched chain alkyl acid ester having the

structure designated



where X is halogen such as bromine, R_5 is defined above with the exception that R_5 may not be a bond, and B is lower alkyl of from 1 to about 7 carbon atoms, preferably ethyl or methyl. This reaction produces a mixture of N-carboxyl esters which may be separated optionally by conventional means such as thin layer chromatography or chromatography on an anion exchange resin and the desired substituted xanthine recovered. The carboxyl ester is then hydrolyzed to produce the free acid. The acid may then be condensed with amino-substituted radioiodinated or radioiodinatable compounds such as the radioiodinatable ring-containing compounds, radioiodinatable aliphatic groups or preradioiodinated compounds described above.

Where a radioiodinatable compound has been produced in any of the foregoing methods, as opposed to a finished tracer, the radioiodinatable compound may be substituted with ^{125}I or ^{131}I in accordance with any of the following methods:

(1) Chloramine T Method of Hunter-Greenwood, W. Hunter, R.C. Greenwood, "Nature", *194*: 495 (1962);
(2) Iodine Monochloride Method, M. Ceska, F. Grossmuller, U. Lundkvist, "Acta Endocrinologia" *64*: 111-125 (1970);
(3) Isotopic Exchange Method, R.E. Counsell, V.V. Ranade, P. Pocha, R.E. Willette, W. Diguilio, "J. Pharmaceut. Sciences" *57*: 1657 (1968);
(4) Electrolytic Iodination, R. Pennisi, U.Rosa, "J. Nuclear Biol. and Medicine" *13*:64 (1964); and
(5) Enzymatic Iodination, H. Van Vanakis, J.J. Langone, L.J. Riceberg, L. Levine, "Cancer Research" *34*:2546-2552 (1974).

The water soluble products of this invention may be iodinated in inert solvents such as water or water-alcohol mixtures.

Separation of unreacted radioactive iodine is accomplished by ion exchange chromatography and the use of aqueous solvents that selectively elute unreacted inorganic iodide and the desired iodinated product.

The preferred radioimmunoassay technique for use with the tracers of this invention is a competitive binding assay which utilizes a precipitating antiserum reagent to separate antibody-bound tracer from unbound tracer.

The procedure is based on the well-known competitive binding radioimmunoassay. In the case of theophylline, nonradioactive theophylline, whether from serum samples, theophylline standards, or controls, competes with a constant amount of ^{125}I theophylline tracer for binding sites on the theophylline antibody, which is held at a limiting concentration. The amount of ^{125}I theophylline tracer which will bind to the antibody is inversely proportional to the amount of non-radioactive theophylline present in the assay tube.

A precipitating reagent solution containing an antibody to antitheophylline is used to immunoprecipitate the antibody-bound ^{125}I theophylline, thus separating bound and unbound tracer. The assay tubes are then centrifuged and the supernatants are decanted. The double antibody-bound ^{125}I theophylline, which is located in the centrifugal pellet, is counted in a well-type, solid crystal gamma counter. A standard curve is constructed and the theophylline concentrations of the samples are interpolated from the standard curve.

The invention will be more fully understood in view of the following examples.

Example 1

A. Synthesis of Theophylline-8-(4-Butyric Acid)

A mixture of 2.0 g of 4,5-diamino-1,3-dimethyl pyrimidine-2,6-dione and 2.68 g of glutaric anhydride in 150 ml of N,N-dimethyl formamide (N,N-DMF) is refluxed for 3 hours under a nitrogen purged Dean-Stark apparatus. The yellow crystals obtained are washed with 300 ml of benzene. Recrystallization is effected by dissolution in boiling water, filtration, cooling and isolation of the yellow-white crystals:

Approximate yield 40%; m.p. 143144°C; main IR peaks 3190, 1760, 1650, 1505, 1415 cm^{-1}; λ_{max}^{MeOH} 209, 275; elemental analysis:

	$C_{11}H_{14}N_4O_4$
Calculated	C 49.62, H 5.30, N 21.04
Found	C 49.55, H 5.50, N 20.99

B. Synthesis of Theophylline-8-(4-Butyryl-N-Histamine)

100 mg of theophylline-8-(4-butyric acid) is placed in a 12 × 75 mm glass test tube and dissolved in 4 ml of N,N-DMF. After chilling on an ice-water bath, 52.5 µl of triethyl amine is added and swirled. This is followed by addition of 44.2 µl of isobutyl chloroformate. The reaction proceeds for 30 minutes. Histamine free base, 46.0 mg, is dissolved in 4 ml of water and is added to the activated theophylline-8-(4-butyric acid) and left at 4°C for 16 hours.

The aqueous layer is applied to an Amberlite XAD-2 gel permeation column, washed with water, and eluted with ethanol which is subsequently concentrated and lyophilized to yield about 10 mg of yellow solid. TLC in 100% ethanol shows a single spot that stains for histamine (Pauly stain).

Example 2

Iodination of theophylline-8-(4-butyryl-N-histamine) is effected by the method of Hunter and Greenwood. 10 µl of a solution of 0.75 mg of the compound of Example 1 in 3.38 mls of a 0.5M phosphate buffer pH 8.0 is placed into a 12 × 75 mm glass tube. To this is added 0.5 mCi of sodium iodide ^{125}I in 5 µl of 0.1 *N* NaOH followed by 10 µl of an aqueous solution of chloramine-T (50 mg in 10 mls of distilled water). After reaction at room temperature for three minutes with occasional swirling, the reaction is quenched by the addition of 10 µl of a solution of sodium metabisulfite (300 mg in 10 ml of distilled water). The desired product, theophylline-8-(4-butyryl-N-[4-^{125}I] histamine), is recovered and separated from unreacted iodide by chromatography on an anion exchange column.

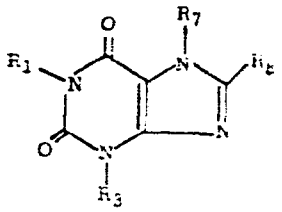
Example 3

The tracer of Example 2 is used as the radiolabeled antigen in the competitive radioimmunoassay generally described above. 25 µl of patient serum is added to a duplicate pair of 12 × 75 mm polypropylene test tubes. Duplicate blank and standard tubes are prepared with 25 µl of 0 µg/ml, 15 µg/ml and 35 µg/ml theophylline solutions. 100 µl of tracer (2.5 µ Ci/15 ml) are added to each tube and the contents mixed gently, followed by 100 µl of rabbit anti-theophylline serum in phosphate buffered saline containing 0.02 M sodium azide and a polymeric precipitation aid. All tubes are then incubated for 15 minutes. 1.0 ml of goat anti-rabbit serum in isotonic phosphate buffer with 0.003 M sodium azide is added to each tube and the contents mixed by careful shaking. All tubes are immediately centrifuged for 10 minutes at a minimum relative centrifugal force of 850 xg in a refrigerated centrifuge at 4-12°C. Each tube is then carefully decanted into a waste receptacle, followed by tapping each tube on an absorbent surface to remove any adhering supernatant. All tubes are then counted in a gamma counter with the window suitably adjusted for ^{125}I.

CLAIMS

1. In a radioimmunoassay for xanthine derivatives in a sample, which method comprises contacting the sample with a known amount of xanthine derivative tracer and an antibody which will selectively bind the tracer and the xanthine derivative, then measuring the degree of binding of the tracer to the antibody, the improvement which comprises using as said xanthine derivative tracer a xanthine compound substituted at at least one of the 1, 3, 7 or 8 positions of the xanthine nucleus by a radioiodinated radical.

2. Compounds useful in the radioimmunoasay of xanthine derivatives, said compounds having the formula:



wherein

(a) at least one R_1, R_3, R_7 or R_8 is a radioiodinated radical; and

(b) if not substituted by a radioiodinated radical the remaining R_1, R_3, R_7 or R_8 groups are otherwise identical to the substituents at these positions in the xanthine derivative which is to be assayed.

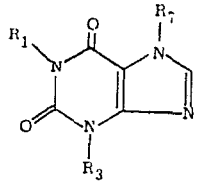
3. The composition of Claim 2 wherein at least one R_1, R_3 or R_7 is a radioiodinated radical.

4. The composition of Claim 2 wherein R_8 is a radioiodinated heterocyclic ring.

5. The composition of Claim 2 wherein the radical is a radioiodinated alkenyl group.

6. The composition of Claim 4 wherein the ring is an imidazole, indole, furan, pyrrole or thiophene radical.

7. Compounds of the formula



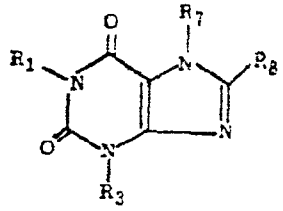
wherein at least one R_1, R_3, R_7 or R_8 is a radioiodinated radical and wherein, if not substituted by a radioiodinated radical, R_1 is hydrogen, acetate or methyl; R_3 is methyl; R_7 is hydrogen, methyl or acetate;

and R_8 is hydrogen.

8. The composition of Claim 7 wherein R_1 and R_3 are methyl.

9. The composition of Claim 7 wherein R_8 is radioiodine.

10. Radioiodinatable xanthine derivatives having the formula:



wherein

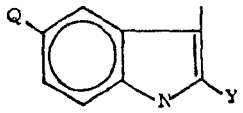
(a) R_1 is an imidazole, pyrrole, thiophene, indole or polyunsaturated alkenyl radical;

(b) R_3 is a nonenzymatic radioiodinatable radical;

(c) R_7 is a pyrrole, furan, thiophene, polyunsaturated alkenyl, imidazole or indole radical, with the proviso that

(1) the imidazole radical has the structure $-L(X)_n$ wherein L is a linking group containing at least one ester, ether, amide or amino bond, X is imidazole and n ranges from 1 to about 10; and

(2) the indole radical has the structure:



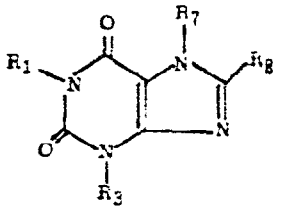
wherein Q is hydrogen or hydroxyl and Y is hydrogen, halo or lower alkyl up to about 7 carbon atoms; and

(d) R_8 is a pyrrole, furan or imidazole radical wherein the imidazole radical is set forth in part (c) (1);

with the further proviso that no more than two of R_1, R_3, R_7 or R_8 are the above radicals and that if R_1, R_3, R_7 or R_8 are not one of the above radicals then R_1 is hydrogen, acetate or methyl; R_3 is methyl; R_7 is hydrogen, acetate or methyl; and R_8 is hydrogen.

11. The derivatives of Claim 10 wherein R_3 is an unsaturated heterocyclic radical or a hydroxy-substituted, unsaturated cyclic hydrocarbon radical.

12. Compounds useful in the radioimmunoassay of xanthene derivatives, said compounds having the formula:

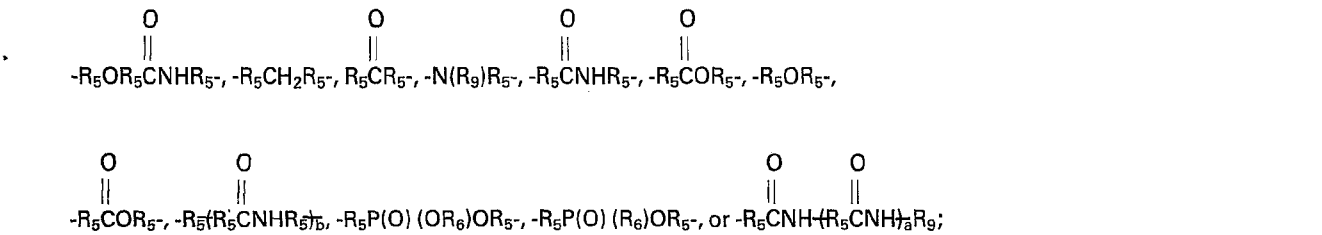


wherein

(a) at least one R_1, R_3, R_7 or R_8 is the group $L(Z)_n$ in which L is a linking group, Z is a radioiodinated ring and n ranges from 1 to about 10; and

(b) if not substituted by said $L(Z)_n$ group the remaining R_1, R_3, R_7 or R_8 groups are otherwise identical to the substituents at these positions in the xanthine derivative to be radioimmunoassayed.

13. The derivative of Claim 12 wherein L is a bond,



$-R_5OR_5\overset{O}{\overset{\|}{C}}NHR_5-$, $-R_5CH_2R_5-$, $R_5\overset{O}{\overset{\|}{C}}R_5-$, $-N(R_9)R_5-$, $-R_5\overset{O}{\overset{\|}{C}}NHR_5-$, $-R_5\overset{O}{\overset{\|}{C}}OR_5-$, $-R_5OR_5-$,

$-R_5\overset{O}{\overset{\|}{C}}OR_5-$, $-R_5\{R_5CNHR_5\}_b$, $-R_5P(O)(OR_6)OR_5-$, $-R_5P(O)(R_6)OR_5-$, or $-R_5CNH\{R_5CNH\}_aR_9$;

and wherein

(i) R_5 is a bond or a substituted or unsubstituted hydrocarbon;

(ii) R_6 is alkyl of from 1 to about 6 carbon atoms;

(iii) R_9 is hydrogen or a substituted or unsubstituted hydrocarbon;

(iv) a ranges from 1 to about 10; and

(v) b is 2 or 3.

14. The derivative of Claim 12 wherein L is a bond,

$$-R_5OR_5\overset{O}{\overset{\|}{C}}NHR_5-,\ -R_5CH_2R_5-,\ -R_5\overset{O}{\overset{\|}{C}}R_5-,\ -N(R_9)R_5-,\ -R_5\overset{O}{\overset{\|}{C}}OR_5-,\ -R_5\overset{O}{\overset{\|}{C}}(R_5NHR_5\overset{O}{\overset{\|}{C}})_bR_5-,\ -R_5OR_5-,$$

$$-R_5\overset{O}{\overset{\|}{C}}OR_5-,\ -R_5P(O)(OR_6)OR_5-,\ -R_5P(O)(R_6)OR_5-,\ \text{or}\ -R_5\overset{O}{\overset{\|}{C}}NH(R_5\overset{O}{\overset{\|}{C}}NH)_aR_9;\ \text{and wherein}$$

(i) R_5 is a bond or a substituted or unsubstituted hydrocarbon;

(ii) R_6 is alkyl of from 1 to about 6 carbon atoms;

(iii) R_9 is hydrogen or a substituted or unsubstituted hydrocarbon;

(iv) a ranges from 1 to about 10; and

(v) b is 2 or 3.

15. The derivative of Claim 12 wherein Z is an imidazole, indole, pyrrole, furan or thiophene radical.

16. The derivative of Claim 12 wherein Z is a radioiodinated heterocycle.

17. The derivative of Claim 13 wherein R_5 is a cyclic, normal or branched chain alkylene or alkenylene, or such alkylene or alkenylene substituted with halo, hydroxy, keto, carboxy, alkoxy, alkoxycarbonyl, amino or alkylamino groups.

18. The derivative of Claim 14 wherein R_5 is a cyclic, normal or branched chain alkylene or alkenylene, or such alkylene or alkenylene substituted with halo, hydroxy, keto, carboxy, alkoxy, alkoxycarbonyl, amino or alkylamino groups.

19. The derivative of Claim 12 wherein Z is a phenol, imidazole, indole, pyrrole, furan or thiophene radical.

20. The derivative of Claim 12 wherein L is a polypeptide.

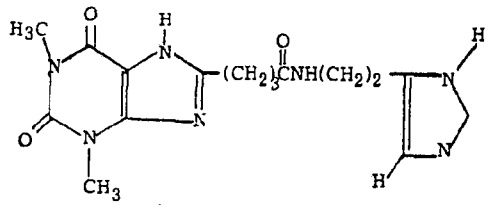
21. The derivative of Claim 12 wherein L is

$$-R_5\overset{O}{\overset{\|}{C}}NHR_5-$$

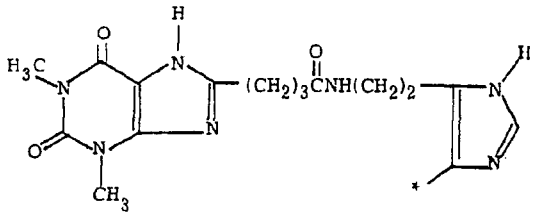
and R_5 is a bond; a cyclic, normal or branched alkylene; or such alkylene substituted with no more than two hydroxy, keto, carboxy, alkoxy, alkoxycarbonyl, amino or alkylamino groups.

22. The derivative of Claim 21 wherein R_5 is alkylene substituted with hydroxy, carboxy or amino.

23.

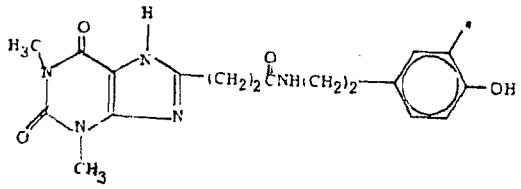


24.



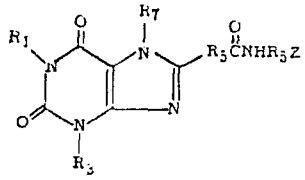
wherein * is radioiodine.

25.



wherein * is radioiodine.

26 A compound having the formula:



wherein

(a) R_1 is hydrogen, acetate or methyl; R_3 is methyl; and R_7 is hydrogen, acetate or methyl;

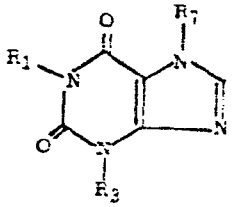
(b) R_5 is a bond; a cyclic, normal or branched chain alkylene or alkenylene; or such alkylene or alkenylene substituted with halo, hydroxy, keto, carboxy, alkoxy, alkoxy-carbonyl, amino or alkylamino groups; and

(c) Z is a radioiodinated phenol or imidazole radical.

27. The compound of Claim 26 wherein Z is a radioiodinated imidazole radical.

28. The method of making a xanthene derivative which comprises

(a) providing an alkali metal salt of a compound having the structure



wherein at last one R_1, R_3 or R_7 is hydrogen, and, if not hydrogen, R_1 and R_7 are acetate or methyl and R_3 is methyl;

(b) reacting the salt with a lower alkyl ester of an ω -halogenated normal or branched chain alkyl acid ester having the structure

wherein R_5 is substituted or unsubstituted hydrocarbon; X is halogen; and B is lower alkyl of from 1 to about 7 carbon atoms.

(c) hydrolyzing the reaction product to form a free acid;

(d) forming a mixed anhydride by reacting the free acid with an activating agent; and

(e) reacting the mixed anhydride with an amino-substituted radioiodinated or radioiodinatable compound.

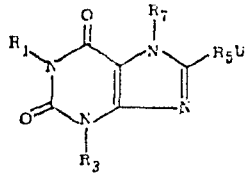
29. The method of Claim 28 wherein R_5 is substituted with no more than two hydroxy, amino or alkoxy substituents.

30. The method of Claim 28 wherein the amino-substituted radioiodinatable compound is tyrosine tyrosinol, 4-(2-aminoethyl) phenol, histidine, histidinol, histamine, and amino-terminated polypeptides containing one or more radioiodinatable rings.

31. The method of Claim 28 including the additional step of radioiodinating the xanthine derivative.

32. The method of making a xanthine derivative which comprises

(a) providing a starting compound having the structure



wherein

(i) R_5 is a bond; a cyclic, normal or branched chain alkylene or alkenylene; or such alkylene or alkenylene substituted with halo, hydroxy, keto, alkoxy, alkoxycarbonyl, carboxyl, amino or alkylamino groups;

(ii) U is carboxyl or amino; and

(iii) R_1, R_3 and R_7 are identical to the substituents at these positions in the xanthine derivative to be radioimmunoassayed;

(b) Providing a radioiodinatable or radioiodinated compound having a carboxyl substituent if U is amino or an amino substituent if U is carboxyl;

(c) forming a mixed anhydride by reacting the carboxyl substituent with an activating agent; and

(d) reacting the mixed anhydride with the amino substituent to form a peptide bond between the radioiodinatable or radioiodinated compound and the starting compound.

33. The method of Claim 32 wherein R_5 contains no more than two hydroxy, amino or alkoxy substituents.

34. The method of Claim 32 wherein the amino-substituted radioiodinatable compound is tyramine, tyrosine, tyrosinol, 4-(2-aminoethyl) phenol, histidine, histidinol, histamine, and amino-terminated polypeptides containing one or more radioiodinatable rings.

35. The method of Claim 32 including the additional step of radioiodinating the xanthine derivative.

36. The method of Claim 32 wherein the amino-substituted radioiodinatable compound is a heterocyclic compound.

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