α-methyl substitution, and it was concluded that this could be explained most satisfactorily in terms of an induced fold, as bulky substituents near the ester group would tend to hinder efficient fold formation. It can be seen from Table III that a similar pattern is observed in the present hydrolysis studies, a marked drop in the rate of hydrolysis occurring on β-methyl substitution of SCh_2, thus supporting the idea of induced-fold formation. Although low rates of hydrolysis are observed for both the L- and D-β-$MeSCh_2$ isomers, their affinities for the enzyme are different (Table I). The isomer with the higher affinity must also have a high activity, and *vice versa*, in order that similar rates of hydrolysis be observed. Conversely, when two compounds have the same affinities, differences in their rates of hydrolysis will reflect differences in relative activities. The high affinity of the L-β-methyl isomer, due possibly to an increase in charge on the ester oxygen caused by electron donation from the methyl group, coupled with its low rate of hydrolysis, indicates that fold formation is essential for activity but not for affinity. The electronic influence will be the same in both β enantiomers, and therefore the low affinity of the D-β-methyl isomer is probably due to steric interference from the methyl group which in this configuration prevents bond formation between the glutamic acid residue and the ester oxygen.

The most active substrate used in the present study was not SCh_2 but L-(−)-α-$MeSCh_2$. An analogous increase in the rate of hydrolysis upon L-α-methyl substitution of BuCh was not observed by Mitchard,[15] although in inhibitor studies using the α- and β-methyl analogs of *p*-aminobenzoylcholine, L-*p*-aminobenzoyl-α-methylcholine was shown to be a more potent competitive inhibitor of PChE than was *p*-aminobenzoylcholine. The D-α-methyl derivative has a high affinity and correspondingly low rate of hydrolysis, the L-α isomer has a lower affinity and is hydrolyzed rapidly, and SCh_2 has a high affiinity and a comparatively high rate of hydrolysis; the activity of the enzyme toward SCh_2 and L-α-$MeSCh_2$ must therefore be considerably higher than toward D-α-$MeSCh_2$. It can be seen that interpretation of structure–activity relationships must be undertaken with great care as the maximum velocity values observed are not necessarily indicative of the more fundamental affinity and activity values. The difference in the affinities of the α-methyl isomers will be due to (i) steric interference and (ii) differences in interaction with the hydrophobic site because the α-methyl group is too far from the ester group to exert any significant electronic influence.

It has been found[14] that β-methyl substitution reduces the pharmacological activity much more than does α-methyl substitution. The observation made during the present study that the rates of enzymic hydrolysis follow the same pattern as the pharmacological results indicate that similarities exist between the receptor site for these compounds and the active site of PChE. The K_i values, however, do not follow this pattern, and no definite conclusion can be reached concerning the nature of these similarities. Although the results obtained in the present study do not show the good correlation between inhibitor and hydrolytic studies which was observed by Mitchard,[15] they do appear to follow the same general pattern, indicating that application of the induced-fit theory to PChE is probably valid.

Acknowledgments.—Receipt of a scholarship from the Department for Scientific and Industrial Research is gratefully acknowledged by Caroline L. Vaughan. Appreciation is given to Dr. J. W. Clitherow for his advice during the initial stages of this work.

Sympathetic Nervous System Blocking Agents. V. Derivatives of Isobutyl-, *t*-Butyl-, and Neopentylguanidine[1,2]

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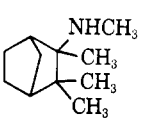
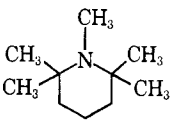
Received June 24, 1968

Guanidines prepared from simple *n*-alkylamines fail to show adrenergic neurone blocking activity, as determined by the effect on the cat nictitating membrane, while guanidines such as *t*-butylguanidine sulfate and neopentylguanidine sulfate are active. *t*-Octylguanidine hydrochloride (Table I, **5**) proved to be the most active member of the alkylguanidine series. It was subjected to extensive pharmacological evaluation and clinical trial. Substitution of one or two methyl groups on the α or β carbons of dialkylaminoalkylguanidines was also investigated. 2-Hexamethyleniminoisobutylguanidine sulfate (**20**) caused a remarkably long blockade of the sympathetic nervous system.

Mecamylamine[3] (I) and pempidine[4] (II) were the first substances found to possess ganglionic blocking activity which were not quaternary ammonium salts. Both are *t*-carbinamines, that is, the nitrogen atom of each is attached to a carbon atom containing three alkyl substituents. This hydrocarbon bulk which surrounds the nitrogen may be of great significance as far as the activity of I and II are concerned and sug-



I



II

(1) Paper IV: J. H. Short and T. D. Darby, *J. Med. Chem.*, **11**, 848 (1968).

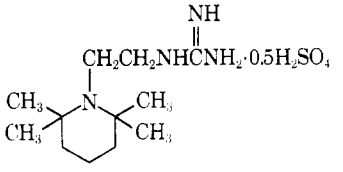
(2) Presented before the Division of Medicinal Chemistry at the 155th National Meeting of the American Chemical Society, San Francisco, Calif., April 1968.

(3) G. A. Stein, M. Sletzinger, H. Arnold, D. Reinhold, W. Gaines, and K. Pfister, III, *J. Am. Chem. Soc.*, **78**, 1514 (1956).

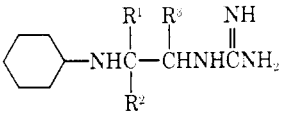
(4) A. Spinks and E. H. P. Young, *Nature*, **181**, 1397 (1958); G. E. Lee, W. R. Wragg, S. J. Corne, N. D. Edge, and H. W. Reading, *ibid.*, **181**, 1717 (1958).

gested to us the idea of synthesizing guanidines (VI, VIII) from "bulky" amines such as 2-dialkylaminoisobutylamines (V, $R^1 = R_2N$) and derivatives of neopentylamine (V, $R^1 = CH_3$, R_2NCH_2) and *t*-butylamine (VII, $R^1 = R_2N$).

Very few guanidines have been reported which possess a *t*-carbinamine moiety. Robertson, Biel, and DiPierro[5] investigated a series of compounds related to pempidine and also containing the guanidine group of which III is a typical example.



III

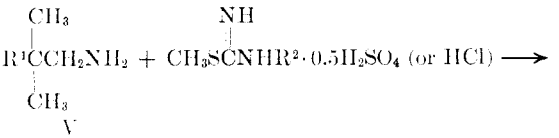


IVa, $R^1 = R^2 = H$; $R^3 = CH_3$
b, $R^1 = CH_3$; $R^2 = R^3 = H$
c, $R^1 = R^2 = CH_3$; $R^3 = H$

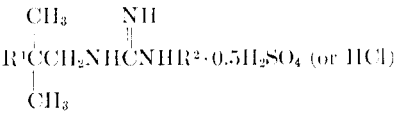
After our work was completed Rand and Wilson[6] reported their studies with several derivatives of 2-cyclohexylaminoethylguanidine as sympathetic nervous system blocking agents. Included were the α-methyl (IVa), the β-methyl (IVb), and the β,β-dimethyl (IVc) derivatives. They found IVa and IVb to be slightly more active than 2-cyclohexylaminoethylguanidine while IVc was slightly less active.

Chemistry.—We first prepared several alkylguanidines, both unbranched and branched chained. These included *n*-butylguanidine sulfate, *n*-octylguanidine sulfate, *t*-butylguanidine sulfate (VIII, $R^1 = R^2 = H$), *t*-octylguanidine (2,4,4-trimethyl-2-pentylguanidine) hydrochloride (VIII, $R^1 = (CH_3)_3C$; $R^2 = H$), neopentylguanidine sulfate (VI, $R^1 = CH_3$; $R^2 = H$), 3,3-dimethyl-*n*-butylguanidine sulfate, 3,5,5-trimethyl-*n*-hexylguanidine sulfate, and 2,2-diethyl-*n*-butylguanidine sulfate. In addition, 2-phenylisobutylguanidine sulfate (VI, $R^1 = C_6H_5$; $R^2 = H$), *p*-chlorophenyl-*t*-butylguanidine hydrochloride (VIII, $R^1 = p$-Cl-C_6H_4; $R^2 = H$), 1-benzyl-3-(*t*-butyl)guanidine hydrochloride (VIII, $R^1 = H$; $R^2 = C_6H_5CH_2$), and 1-methyl-3-(*t*-octyl)guanidine hydrochloride (VIII, $R^1 = (CH_3)_3C$; $R^2 = CH_3$) were prepared.

Method A

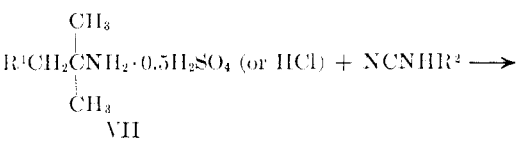


V

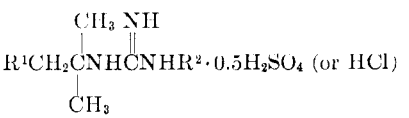


VI

Method B



VII



VIII

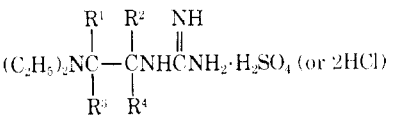
The guanidines possessing a methylene group adjacent to the nitrogen atom could be prepared from the appropriate amine and 2-methyl-2-thiopseudourea sulfate (method A). The unbranched amines and those amines with an ethylene group adjacent to the nitrogen atom (branching at the γ carbon) formed guanidines at room temperature, while neopentylamine (V, $R^1 = CH_3$) and the other amines with branching at the β carbon formed the desired guanidines only at higher temperatures.

Method A was unsuccessful with *t*-butylamine (VII, $R^1 = H$) and related compounds in which branching occurs at the α carbon. Tsuji and Ueda[7] had previously commented on the failure of *t*-butylamine, dimethylamino-*t*-butylamine, and piperidino-*t*-butylamine to react with 2-methyl-2-thiopseudourea sulfate to form the corresponding guanidines.

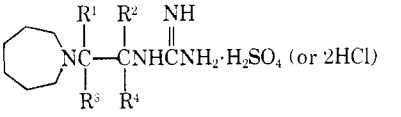
Variations of method A employing 2-methylpseudourea sulfate (or hydrochloride), 2,5-dimethyl-1-guanylpyrazole hydrochloride,[8] and 1-chloroformamidine hydrochloride[9] were uniformly unsuccessful with *t*-butylamine and its derivatives (VII). These guanidines (VIII) were prepared by allowing the amine hydrochlorides (monoamines) to react with cyanamide (method B). With the diamines best results were achieved by dissolving the amine in water, adding only 1 equiv of HCl, and allowing the "monohydrochloride" to react with cyanamide.

Neopentylguanidine sulfate (VI, $R^1 = CH_3$; $R^2 = H$), *t*-butylguanidine sulfate (VIII, $R^1 = R^2 = H$), and *t*-octylguanidine hydrochloride (VIII, $R^1 = (CH_3)_3C$; $R^2 = H$) showed significant activity, while *n*-butylguanidine sulfate and *n*-octylguanidine sulfate were inactive (see Structure–Activity Relationships section). These results encouraged us to extend this line of investigation to the 2-dialkylaminoethylguanidine series.

Earlier we found 2-diethylaminoethylguanidine sulfate (IX, $R^1 = R^2 = R^3 = R^4 = H$) to be active,[8] and we decided to investigate the effect on activity of substitution of methyl groups on the ethylene chain. Similar homologs of hexamethyleniminoethylguanidine sulfate (X, $R^1 = R^2 = R^3 = R^4 = H$), also known to be active,[10] were prepared.



IX



X

2-Diethylamino-*n*-propylguanidine sulfate (IX, $R^1 = CH_3$; $R^2 = R^3 = R^4 = H$) and 2-diethylamino-1-

(5) J. E. Robertson, J. H. Biel, and F. DiPierro, *J. Med. Chem.*, **6**, 381 (1963).

(6) M. J. Rand and J. Wilson, *European J. Pharmacol.*, **1**, 200 (1967).

(7) T. Tsuji and T. Ueda, *Chem. Pharm. Bull.* (Tokyo), **12**, 946 (1964).

(8) J. H. Short, C. Biermacher, D. A. Dunnigan, and T. D. Leth, *J. Med. Chem.*, **6**, 275 (1963).

(9) The compound was prepared in the manner described in the Experimental Section for the *t*-butyl homolog. T. B. Johnson and J. M. Sprague, *J. Am. Chem. Soc.*, **61**, 176 (1939), reported mp 182–183°.

(10) R. P. Mull, M. E. Egbert, and M. R. Dapero, *J. Org. Chem.*, **25**, 1953 (1960).

methylethylguanidine sulfate (IX, $R^2 = CH_3$; $R^1 = R^3 = R^4 = H$) were prepared by methods A and B, respectively. The amine required for the latter guanidine was prepared by reductive alkylation of ammonia with diethylaminoacetone.

Diethylamino-*t*-butylguanidine dihydrochloride (IX, $R^1 = R^3 = H$; $R^2 = R^4 = CH_3$) was prepared by method B, while method A was used to prepare the isomeric 2-diethylaminoisobutylguanidine sulfate (IX, $R^1 = R^3 = CH_3$; $R^2 = R^4 = H$)

Diethylamino-*t*-butylamine (VII, $R^1 = (C_2H_5)_2N$) was prepared by reduction of the nitro compound obtained by allowing diethylamine to react with 2-methyl-2-nitro-1-propanol. The diamine was also obtained when diethylamine was allowed to react with 2,2-dimethylaziridine.

Reaction between acetone cyanohydrin and diethylamine gave 2-diethylaminoisobutyronitrile. Attempts to reduce the latter with $LiAlH_4$ and by catalytic means gave diethylisopropylamine as the only isolable product. The nitrile, however, was hydrolyzed successfully to the corresponding amide and reduction of the latter with diborane gave the desired 2-diethylaminoisobutylamine (V, $R^1 = (C_2H_5)_2N$). $LiAlH_4$ also effected reduction of the amide, but in much lower yield.

Hexamethylenimino-*t*-butylamine

VII, $R^1 = (CH_2)_6N$

and 2-hexamethyleniminoisobutylamine

V, $R^1 = (CH_2)_6N$

were prepared in the same manner as the corresponding diethyl analogs. The amines, in turn, were converted to hexamethylenimino-*t*-butylguanidine dihydrochloride (X, $R^1 = R^3 = H$; $R^2 = R^4 = CH_3$) and 2-hexamethyleniminoisobutylguanidine sulfate (X, $R^1 = R^3 = CH_3$; $R^2 = R^4 = H$) by methods B and A, respectively.

The reaction between N-methylpiperazine and acetone cyanohydrin gave the expected nitrile, which was hydrolyzed to the corresponding amide, and the latter then was reduced to 2-(4-methylpiperazino)isobutylamine.

V, $R^1 = CH_3N\langle\rangle N$

The amine was transformed in the usual manner to 2-(4-methylpiperazino)isobutylguanidine sulfate.

VI, $R^1 = CH_3N\langle\rangle N$; $R^2 = H$

Diethylaminoneopentylamine was prepared by reductive alkylation of NH_3 with diethylaminopivaldehyde. Method A was used to convert the amine into diethylaminoneopentylguanidine sulfate (VI, $R^1 = (C_2H_5)_2NCH_2$; $R^2 = H$).

In our earlier work[8] we had observed that replacement of the guanidine hydrogens of 2-diethylaminoethylguanidine with alkyl groups led to less active or inactive compounds. Nevertheless we prepared several 1,3-disubstituted guanidines in which one substituent was a dialkylaminoalkyl group and the other was a branched alkyl group. 1-(*t*-Butyl)-3-(2-diethylaminoethyl)guanidine dihydrochloride was obtained by the reaction of diethylaminoethylamine with either *t*-butylcyanamide (method B) or with 3-(*t*-butyl)-2-methyl-2-thiopseudourea hydrochloride (method A). The same amine was allowed to react with *t*-octylcyanamide or with 2-methyl-3-(*t*-octyl)-2-thiopseudourea hydrochloride to give 1-(2-diethylaminoethyl)-3-(*t*-octyl)guanidine dihydrochloride.

Method B is the more practical method for obtaining the last two guanidines since it is a one-step procedure. Preparation of these guanidines by method A involves a sequence of three reactions, but was of interest from a chemical standpoint. HCl could be added to *t*-butylcyanamide and *t*-octylcyanamide to give, respectively, N-(*t*-butyl)-1-chloroformamidine hydrochloride and 1-chloro-N-(*t*-octyl)formamidine hydrochloride. Neither of the latter compounds gave the desired guanidines when allowed to react with diethylaminoethylamine. They did, however, react with methanethiol or ethanethiol to give the expected thiopseudoureas, and these underwent reaction in the normal manner, as noted above, to give the desired guanidines, identical in every respect with the substances obtained directly from the amine and the cyanamides.

2-Hexamethyleniminoisobutylamine was allowed to react with *t*-butylcyanamide and *t*-octylcyanamide to give, respectively, 1-(*t*-butyl)-3-(2-hexamethyleniminoisobutyl)guanidine dihydrochloride

VI, $R^1 = (CH_2)_6N$; $R^2 = (CH_3)_3C$

and 1-(2-hexamethyleniminoisobutyl)-3-(*t*-octyl)guanidine dihydrochloride.

VI, $R^1 = (CH_2)_6N$; $R^2 = (CH_3)_3CCH_2C(CH_3)_2$

The guanidine from 1-(2-aminoethyl)-4-methylpiperazine was found to be active,[8] and that amine was also allowed to react with *t*-butylcyanamide to give the expected disubstituted guanidine.

The guanidines are tabulated in Table I.

Pharmacology.—The guanidines were examined by the oral route for their effect on the cat nictitating membrane in the manner previously described.[1,8] The results are compiled in Table I.

2-Hexamethyleniminoisobutylguanidine sulfate (Table I, **20**), when screened at 30 mg/kg, caused a ++ prolapse lasting for 8–9 days. Decreasing the dose to 20 mg/kg did not decrease the duration of the prolapse. It is the only compound we have ever tested that caused a prolapse lasting more than 7 days. It proved to be effective in lowering blood pressure in both renal and neurogenic hypertensive dogs, but it was not effective in doses smaller than 10 mg/kg. Since 2-(2-methylthioethylamino)ethylguanidine sulfate caused a significant decrease in the blood pressure of hypertensive dogs at 2 mg/kg,[1] the latter was chosen for further pharmacological evaluation and clinical trial.

t-Octylguanidine hydrochloride (**5**) was one of the few compounds we have screened which, like guanethidine, causes a +++ prolapse at 30 mg/kg, and, further, it is the only compound we have observed to have a significant effect at 2 mg/kg. It proved to be

Table I: Guanidines

$$R^1NHCNHR^2 \quad (NH)$$

No.	R^1	R^2	Salt	Mp, °C	Method	Recrystn solvent[a]	Formula[b]	Dose, mg/kg	Effect on nictitating membrane[b]	Duration, hr
1	n-C_4H_9	H	$0.5H_2SO_4$	215.5–216	A[c]	C		30	0	Fatal
								5	0	
2	n-C_8H_{17}	H	$0.5H_2SO_4$	251–252	A	D	$C_9H_{21}N_3 \cdot 0.5H_2SO_4$	30	0	
3	t-C_4H_9	H	$0.5H_2SO_4$	245–246	B[d]	E	$C_5H_{13}N_3 \cdot 0.5H_2SO_4$	30	++	8
								15	++	8
4	t-C_4H_9	$C_6H_5CH_2$	HCl	169.5–170.5	B[e]	E	$C_{12}H_{19}N_3 \cdot HCl$	30	0	
5	t-C_8H_{17}[f]	H	HCl	194.5–195.5	B[g]	E	$C_9H_{21}N_3 \cdot HCl$	30	+++	72
								10	++	72
								2	++	48
								1	+	8
6	t-C_8H_{17}	CH_3	HCl	134–136	B[g]	E	$C_{10}H_{23}N_3 \cdot HCl$	30	++	72
								15	0	
7	$(CH_3)_3CCH_2$	H	$0.5H_2SO_4$	282.5–283.5	A	D	$C_6H_{15}N_3 \cdot 0.5H_2SO_4$	30	++	48
								15	++	8
8	$(CH_3)_3CCH_2CH_2$	H	$0.5H_2SO_4$	314–315	A	K	$C_7H_{17}N_3 \cdot 0.5H_2SO_4$	30	0	
9	$(C_2H_5)_3CCH_2$	H	$0.5H_2SO_4$	281.5–283	A	F	$C_9H_{21}N_3 \cdot 0.5H_2SO_4$	30	++	48[h]
								15	++	72
10	$(CH_3)_3CCH_2CH(CH_3)CH_2CH_2$	H	$0.5H_2SO_4$	278.5–279.5	A[i]	G	$C_{10}H_{23}N_3 \cdot 0.5H_2SO_4$	30	0	
11	$C_6H_5C(CH_3)_2CH_2$	H	$0.5H_2SO_4$	251–253	A	K	$C_{11}H_{17}N_3 \cdot 0.5H_2SO_4$	30	0	
12	p-Cl-$C_6H_4CH_2C(CH_3)_2$	H	HCl	220–220.5	B[j]	E	$C_{11}H_{16}ClN_3 \cdot HCl$	30	0	
13	$(C_2H_5)_2NCH_2C(CH_3)_2CH_2$	H	$0.5H_2SO_4$	221–223	A[k]	J	$C_{10}H_{24}N_4 \cdot 0.5H_2SO_4$	30	++	48
								15	++	48
								10	+	48
								5	+	4

$$AmC(R^3)(R^4)CNHCNHR^5 \quad (NH)$$

No.	Am	R^1	R^2	R^3	R^4	R^5							
14	$(C_2H_5)_2N$	CH_3	H	H	H	H	$0.5H_2SO_4$	235–237	A	J	$C_8H_{20}N_4 \cdot 0.5H_2SO_4$	30	++	36
15	$(C_2H_5)_2N$	H	CH_3	H	H	H	H_2SO_4	256.5–257.5	B	J	$C_8H_{20}N_4 \cdot H_2SO_4$	30	+	24
16	$(C_2H_5)_2N$	CH_3	H	CH_3	H	H	H_2SO_4	284.5–285.5	A	G	$C_9H_{22}N_4 \cdot H_2SO_4$	30	++	96
												15	++	80
												10	++	32
17	$(C_2H_5)_2N$	H	CH_3	H	CH_3	H	2HCl	233–235	B[l]	K	$C_9H_{22}N_4 \cdot 2HCl$	30	++	50
												15	+	32
18	$(C_2H_5)_2N$	H	H	H	H	t-C_4H_9	2HCl	212–213	A, B[e]	E	$C_{11}H_{26}N_4 \cdot 2HCl$	30	0	
19	$(C_2H_5)_2N$	H	H	H	H	t-C_8H_{17}	2HCl	179.5–180.5	A, B[e]	E	$C_{15}H_{34}N_4 \cdot 2HCl$	30	0	
20	$(CH_2)_6N$	CH_3	H	CH_3	H	H	$0.5H_2SO_4$	220–223	A	D	$C_{11}H_{24}N_4 \cdot 0.5H_2SO_4$	30	++	216
												30	++	192
												20	++	216
												10	++	72
												10	++	48
												5	++	48
												5	++	32
												2.5	0	

21	$(CH_3)_2N$	H	CH_3	H	CH_3	H	2HCl	214–216	B[m]	H	$C_{11}H_{24}N_4 \cdot 2HCl$	30	++	6
22	$(CH_3)_2N$	CH_3	H	CH_3	H	*t*-C_4H_9	2HCl	232–233	B[e]	E	$C_{15}H_{32}N_4 \cdot 2HCl$	30	0	
23	$(CH_3)_2N$	CH_3	H	CH_3	H	*t*-C_8H_{17}	2HCl	197.5–198.5	B[e]	E	$C_{19}H_{40}N_4 \cdot 2HCl$	30	0	
24	CH_3N N	H	H	H	H	*t*-C_4H_9	$3C_4H_4O_4$[n]	141–143	A[o]	E	$C_{12}H_{27}N_5 \cdot C_{12}H_{12}O_{12}$	30	0	
25	CH_3N N	CH_3	H	CH_3	H	H	$1.5H_2SO_4$	224–226	A	G	$C_{10}H_{23}N_5 \cdot 1.5H_2SO_4$	30	0	
26	Guanethidine											30	+++	168
												10	++	108
												5	+	8
												2.5		0

[a] C, H_2O–Me_2CO; D, H_2O; E, EtOH–Me_2CO; F, EtOH–Skellysolve B; G, H_2O–MeOH; H, EtOH; J, MeOH–Me_2CO; K, H_2O–EtOH. [b] The degree of prolapse is indicated as follows: +, one-fourth of the eye covered by the membrane; ++, one-half, +++, three-quarters. [c] R. B. Fearing and S. W. Fox, *J. Am. Chem. Soc.*, **76**, 4382 (1954), reported mp 210–211°. [d] This guanidine was prepared by method B from *t*-butylcyanamide and NH_4Cl and it was converted to the sulfate with Ag_2SO_4. [e] Prepared by method B from *t*-butylcyanamide or *t*-octylcyanamide and the appropriate amine. Sufficient ethanol was added to form a homogeneous solution. [f] *t*-C_8H_{17} = 2,4,4-trimethyl-2-pentyl. [g] The reaction of *t*-octylcyanamide with NH_4Cl and with $MeNH_2Cl$ is described in detail by L. S. Luskin and J. H. Short, U. S. Patent 3,140,231 (July 7, 1964); *Chem. Abstr.*, **61**, 6927 (1964). The *t*-octylcyanamide was prepared in these laboratories by Mr. Vincent Johnson from *t*-octylamine (Rohm and Haas Co.) and ClCN. [h] The cat receiving the 30-mg/kg dose suffered emesis which accounts for its being more effective at 15 mg/kg. [i] The amine was obtained from Rohm and Haas Co. It has been described by W. M. Bruner, *Ind. Eng. Chem.*, **41**, 2860 (1949). [j] *p*-Chloro-α,α-dimethylphenethylamine was converted to the HCl salt, [G. B. Bachman, H. B. Hass, and G. O. Platau, *J. Am. Chem. Soc.*, **76**, 3972 (1954)] and the salt was allowed to react with cyanamide. [k] The required amine was prepared by reductive alkylation of NH_3 with diethylaminopivaldehyde (method E) and it has been described in a previous report from these laboratories: M. Freifelder and Y. H. Ng, *J. Med. Chem.*, **8**, 122 (1965). [l] The required amine was prepared by the reduction of the corresponding nitro compound (method E),[19] and by the reaction between diethylamine and 2,2-dimethylaziridine (Experimental Section). [m] The reaction was run in the manner of method B except that the solution was heated under reflux for 4 hr instead of at 180°. [n] $C_4H_4O_4$ is fumaric acid. [o] The reaction was run in *t*-BuOH. The solvent was removed and the residual oil was dissolved in water. The solution was made alkaline with 50% NaOH; the free base was taken up in $CHCl_3$ and converted to the fumarate salt. The required amine, 1-(2-aminoethyl)-4-methylpiperazine, has been described.[8] [p] All compounds were analyzed for C, H, N.

effective in hypertensive dogs, and was subjected to extensive pharmacological evaluation.[11]

Clinical studies showed that **5** was less toxic and caused fewer side effects than guanethidine, but it did not lower blood pressure in hypertensive individuals with the same effectiveness and consistency as did guanethidine.

Structure–Activity Relationships.—The activity of *t*-butylguanidine sulfate (Table I, **3**) and neopentylguanidine sulfate (**7**) contrasted strongly with the lack of activity seen with *n*-butylguanidine sulfate (**1**) and *n*-octylguanidine sulfate (**2**). A longer duration of activity was seen with **7** than with **3**, indicating that branching at the β carbon might be more desirable than branching at the α carbon.

These first results encouraged us to proceed further with such branched-chain guanidines.

The failure of 3,3-dimethyl-*n*-butylguanidine sulfate (**8**) to exhibit the desired activity indicated that branching beyond the β carbon was not efficacious for activity. The inactivity of 3,5,5-trimethyl-*n*-hexylguanidine sulfate (**10**) confirmed this conclusion. This principle was confirmed further by finding that 2,2-diethyl-*n*-butylguanidine sulfate (**9**) was active. Therefore, further work was limited to preparation of guanidines possessing branching at either the α or β carbons.

t-Octylguanidine hydrochloride (**5**) proved to be very active (see Pharmacology section). 1-Methyl-3-(*t*-octyl)guanidine hydrochloride (**6**) was somewhat less active. Reduction of activity in a disubstituted guanidine of this sort when compared with the monosubstituted homolog is in line with previous observations.[8,12]

Two compounds containing aromatic groups, namely 2-phenylisobutylguanidine sulfate (**11**) and *p*-chlorophenyl-*t*-butylguanidine hydrochloride (**12**), proved to be inactive. In contrast, 2-(*p*-chlorophenyl)ethylguanidine hydrochloride[12] had previously been found to have activity, but of short duration.

In the dialkylaminoalkylguanidine series 2-diethylamino-*n*-propylguanidine sulfate (**14**) and 2-diethylamino-1-methylethylguanidine sulfate (**15**) both proved to have substantial activity, but less than 2-diethylaminoethylguanidine sulfate.[8] Diethylamino-*t*-butylguanidine dihydrochloride (**17**) proved to be about as active as 2-diethylaminoethylguanidine sulfate, while its isomer, 2-diethylaminoisobutylguanidine sulfate (**16**), proved to be considerably more active.

A homolog of **16** and **17**, diethylaminoneopentylguanidine sulfate (**13**), was about as active as **17**.

Hexamethylenimino-*t*-butylguanidine dihydrochloride (**21**) proved to have surprisingly little activity, but its isomer, 2-hexamethyleniminoisobutylguanidine sulfate (**20**), showed the longest duration of activity of any guanidine we have tested (see Pharmacology section).

The structure–activity relationships outlined here and in the previous papers in this series led us to predict that 2-(4-methylpiperazino)isobutylguanidine sulfate (**25**) might show exceptional activity. As often happens in medicinal chemistry our prediction proved wrong, since **25** failed to cause a prolapse at 30 mg/kg.

We found in our previous work with dialkylaminoalkylguanidines,[8] as well as in the benzylguanidine

(11) H. G. Schoepke, H. D. Brondyk, L. H. Wiemeler, and J. L. Schmidt, *Arch. Intern. Pharmacodyn.*, **153**, 185 (1965).

(12) J. H. Short and T. D. Darby, *J. Med. Chem.*, **10**, 833 (1967).

series,[12] that one methyl group could be substituted on a guanidine nitrogen (to give 1,3-disubstituted guanidines) without losing activity (*cf.* **5** and **6**), but incorporation of larger *n*-alkyl groups led to inactive compounds. We were interested, therefore, in determining if 1,3-disubstituted guanidines containing a dialkylaminoalkyl group and a branched-chain alkyl group such as a *t*-butyl or *t*-octyl group would possess activity. Five such compounds were prepared (**18**, **19**, **22**–**24**) and were found to be uniformly inactive confirming once again that monosubstituted guanidines are, in all cases, superior to di- and polysubstituted ones.

Testing of the compounds by the oral route raises the question whether a compound might fail to cause a prolapse, not because it is intrinsically inactive, but because it is not absorbed. The ratio of oral toxicity to intraperitoneal toxicity gives an indication of the degree of oral absorption. We have not determined the LD_{50}'s of the compounds described here, but routine toxicity data in mice can give us an approximate oral–intraperitoneal ratio. For example, **1** caused no deaths (0/3) in mice at 50 mg/kg, 2/3 deaths at 75 mg/kg, and 3/3 at 100 mg/kg by the intraperitoneal route. By the oral route no deaths (0/3) occurred at 75 mg/kg while 3/3 died at 100 mg/kg. These data give an oral–intraperitoneal ratio of about 2:1, indicating that **1** is well absorbed. This ratio is not typical, however. None of the other guanidines are as well absorbed. For **2** the ratio is about 10:1 (intraperitoneal, 0/3, 30 mg/kg; 1/3, 50 mg/kg; 3/3, 75 mg/kg; oral, 0/3, 300 mg/kg; 2/3, 500 mg/kg; 3/3, 750 mg/kg). The remaining inactive compounds all had oral–intraperitoneal toxicity ratios between 5:1 and 10:1 except for **18** which had a ratio of 20:1.

Ratios for the active compounds were comparable. For **3**, **5**, and **7** the ratios were 5:1 or less. Six active compounds (**6**, **14**–**17**, and **21**) had ratios between 6:1 and 10:1. Compounds **9** and **13** had ratios of about 15:1, while our most active compound, **20**, had a ratio of about 20:1.

The above information indicates that all the guanidines in this series are absorbed to some extent following oral administration, and that we are not likely to have missed a very active compound because of lack of absorption.

This work had led to the following conclusions: (1) alkyl substituents on C-1 or C-2 of simple alkylguanidines lead to active compounds; (2) methyl substituents at C-1 of dialkylaminoalkylguanidines have little effect on activity, while substituents at C-2 usually enhance activity; (3) incorporation of a second substituent (*t*-butyl or *t*-octyl) gives inactive compounds.

Experimental Section[13]

N-(*t*-Butyl)-1-chloroformamidine Hydrochloride.—A solution of 49 g (0.5 mole) of *t*-butylcyanamide in 500 ml of dry Et_2O was stirred as 400 ml of 10% ethereal HCl was added during 2 hr. After standing overnight at room temperture a white solid was collected. The yield was 78 g (91%), mp 114–117°. Recrystallization from $CHCl_3$–THF gave thick colorless prisms melting at 115–117°, lit.[14] mp 110–113°.

3-(*t*-Butyl)-2-ethyl-2-thiopseudourea Hydrochloride.—A suspension of 85 g (0.5 mole) of N-(*t*-butyl)-1-chloroformamidine hydrochloride and 62 g (1.0 mole) of ethanethiol in 500 ml of 1,2-dimethoxyethane was heated under reflux for 8 hr. The solution was chilled to obtain 66.2 g of white solid, mp 130–132°. Concentrating and chilling the filtrate gave an additional 15 g of product, total yield 81.2 g (83%). A recrystallized portion (Me_2CO) melted at 131–132°. *Anal.* ($C_7H_{16}N_2S \cdot HCl$) C, H, N.

1-Chloro-N-(*t*-octyl)formamidine Hydrochloride.—*t*-Octylcyanamide (31 g, 0.2 mole) was allowed to react with HCl in the manner described above for the *t*-butyl homolog. The yield of product was 40 g (88%), mp 123–126°. *Anal.* ($C_9H_{19}ClN_2 \cdot HCl$) C, H, N.

2-Methyl-3-(*t*-octyl)-2-thiopseudourea Hydrochloride.—A suspension of 113.6 g (0.5 mole) of 1-chloro-N-(*t*-octyl)formamidine hydrochloride in 750 ml of 1,2-dimethoxyethane and 48 g (1.0 mole) of methanethiol was heated under reflux for 6 hr. The solution was taken to dryness and the residue was dissolved in 200 ml of boiling acetone. The solution was chilled to obtain 64.6 g (54%) of white, glistening leaflets, mp 145–147°. Recrystallization from EtOH–Me_2CO raised the melting point to 148.5–149°. *Anal.* ($C_{10}H_{22}N_2S \cdot HCl$) C, H, N.

Preparation of Guanidines. Method A.—A solution of 0.1 mole of the amine and 14 g (0.05 mole) of 2-methyl-2-thiopseudourea sulfate in 25–50 ml of H_2O was heated under reflux for 2–18 hr. The solution was taken to dryness and the residue was crystallized from an appropriate solvent. In a few cases the guanidine precipitated on chilling the reaction solution. Some of the amines were not water soluble and sufficient EtOH was added to form a solution.[15] When 3-(*t*-butyl)-2-ethyl- and 3-(*t*-octyl)-2-methyl-2-thiopseudourea hydrochlorides were used, 0.05 mole of the pseudourea was allowed to react as above with an equivalent amount of the amine in 100 ml of *t*-BuOH. The guanidines are described in Table I.

The use of N-(*t*-butyl)-1-chloroformamidine hydrochloride, and its *t*-octyl homolog, failed to give the guanidines when allowed to react with amines in the above manner.

Method B.—The amine hydrochloride (monoamines) (0.1 mole) or the free amine (diamines) was dissolved in 50 ml of H_2O. To the diamine solutions was added 0.1 mole of HCl or 0.05 mole of H_2SO_4. A slight excess of cyanamide (0.11 mole) was added. When *t*-butyl- and *t*-octylcyanamides were used, enough EtOH was added to form a solution. The reaction solution was placed in a silicone oil bath and the temperature was allowed to rise to 180° during 1 hr as the solvent distilled, and then kept at 180° for 2 hr. The guanidines from the diamines were dissolved in water, a second equivalent of acid (HCl or H_2SO_4) was added, and the solution was taken to dryness. The residue was crystallized from an appropriate solvent. The guanidines are described in Table I.

1-Hexamethylenimino-2-methyl-2-nitropropane.—A solution of 99 g (1.0 mole) of hexamethylenimine and 119 g (1.0 mole) of 1-hydroxy-2-methyl-2-nitropropane in 500 ml of PhH was heated under reflux with a water separator until no further H_2O separated (48–72 hr). The solvent was removed and the residue was distilled to render 180 g (90%) of colorless oil, bp 98–101° (1.5 mm), which solidified, mp 38–40°. *Anal.* ($C_{10}H_{20}N_2O_2$) C, H, N.

2-(Substituted amino)isobutyronitriles. Method C.—A solution of 1.0 mole of the amine and 1.0 mole of acetone cyanohydrin in 250 ml of dry PhH was heated under reflux until no more water collected in a water separator (about 18 hr). The solvent was removed and the residue was distilled. The nitriles are described in Table II.

2-(Substituted amino)isobutyramides. Method D.—A solution containing 5 ml of 90% H_2SO_4 for each gram of nitrile was heated on the steam bath for 0.5–2.0 hr. The solution was poured onto ice and made basic with aqueous NH_3. The amide was collected on a filter if it was a solid or taken up in $CHCl_3$, dried, and distilled. The amides are described in Table II.

Amines by Reductive Alkylation of Ketones. Method E.—The ketone was dissolved in EtOH (4 ml/g) and liquid NH_3 was

(13) Melting points were determined in capillary tubes in a silicone oil bath and are corrected. Where analyses are indicated only by symbols of the elements, analytical results for those elements are within ±0.3% of the theoretical values.

(14) M. Seefelder, German Patent 1,119,258 (Dec 14, 1961); *Chem. Abstr.*, **56**, 11450 (1962).

(15) The use of ethanol to take the water-insoluble amines into solution does not appear to be essential. Reaction of 2,2-diethyl-*n*-butylamine (0.05 mole) with 2-methyl-2-thiopseudourea (0.025 mole) sulfate takes place in H_2O (25 ml) to give a 55.5% yield of the expected guanidine even though the reaction mixture consists of two layers at the start. A comparable yield (59%) of the guanidine was obtained when the reaction was effected in 80% EtOH (25 ml). The reaction does not proceed satisfactorily in absolute EtOH (25 ml) because of the insolubility of 2-methyl-2-thiopseudourea sulfate in EtOH. The more soluble hydrochloride salt, on the other hand, gives satisfactory results in EtOH.[8]

TABLE II
NITRILES AND AMIDES

No.	R	Mp or bp, °C (mm)	$n^{25}D$	Method	Yield, %	Formula	Analyses
			$RCCN$ (CH_3)				
1	$(C_2H_5)_2N$	76–79 (28)[a]	1.4302	C	57		
2	$(CH_2)_5N$	82–84 (1)	1.4662	C	75	$C_{10}H_{18}N_2$	C, H, N
3	CH_3N N	108–110 (1)[b]		C	40	$C_9H_{17}N_3$	C, H
			$RC(CH_3)_2CONH_2$				
4	$(C_2H_5)_2N$	107–108 (7)	1.4600	D	78	$C_8H_{18}N_2O$	C, H, N
5	$(CH_2)_5N$	94.5–96[c]		D	55	$C_{10}H_{20}N_2O$	C, H, N
6	CH_3N N	96–97		D[d]	60	$C_9H_{19}N_3O$	C, H, N

[a] R. A. Jacobson, *J. Am. Chem. Soc.*, **67**, 1996 (1945), reported bp 66–68° (14 mm) and $n^{25}D$ 1.4312. [b] The distillate solidified and melted at 59–60° after being crystallized from Skellysolve B. [c] The amide was crystallized from pentane. [d] The acid solution was poured slowly onto ice to avoid generation of too much heat which causes the amide to decompose. Neutralization was effected with solid K_2CO_3 to keep the volume low because of the water solubility of the amide. It was taken up in $CHCl_3$ and evaporated, and the residue was crystallized from Skellysolve B.

TABLE III
AMINES
RNH_2

No.	R	Bp, °C (mm)	$n^{25}D$	Method	Yield, %	Formula	Analyses
1	$(CH_3)_3CCH_2CH_2$	115 (760)[a]	1.4095	F	66		
2	$(C_2H_5)_3CCH_2$	166–168 (760)	1.4391	*b*	65	$C_8H_{19}N$	C, H, N
3	$C_6H_5C(CH_3)_2CH_2$	106–108 (15)	1.5161	F[g]	76	$C_{10}H_{15}N$	N
4	$(C_2H_5)_2NCH_2CH(CH_3)$	152–154 (760)[c]	1.4275	E	69		
5	$(C_2H_5)_2NC(CH_3)_2CH_2$	48–51 (7) 176–178 (760)	1.4440	F[d]	50	$C_8H_{20}N_2$	C, H, N
6	$(CH_2)_5NC(CH_3)_2CH_2$	56–58 (0.3)	1.4792	F	85	$C_{10}H_{22}N_2$	C, H, N
7	$(CH_2)_5NCH_2C(CH_3)_2$	78–81 (6)	1.4660	E[e]	81	$C_{10}H_{22}N_2$	C, H, N
8	CH_3N $NC(CH_3)_2CH_2$	58–59 (0.3)	1.4778	F[f]	94	$C_9H_{21}N_3$	C, H, N

[a] A. P. Howe and H. B. Hass, *Ind. Eng. Chem.*, **38**, 251 (1946), reported bp 112.8–112.9° (745 mm), $n^{25}D$ 1.4122. The starting material, 3,3-dimethyl-*n*-butyramide, was prepared according to the procedure of A. H. Homeyer, F. C. Whitmore, and V. H. Wellingford, *J. Am. Chem. Soc.*, **55**, 4209 (1933). [b] Triethylacetonitrile (Benzol Products Co.) was reduced with $LiAlH_4$ in the manner previously described for other nitriles.[12] [c] L. Haskelberg, *J. Am. Chem. Soc.*, **70**, 2811 (1948), reported bp 154° (760 mm). [d] The yield of amine was 21% when the amide was reduced with $LiAlH_4$. [e] The amine was prepared by reduction of the corresponding nitro compound (Experimental Section) in the manner of method E except that liquid NH_3 was not added. [f] The trihydrochloride melts at 239–242°. [g] The HCl salt melts at 200–202°. It was recrystallized from MeOH–Et_2O. The starting material, α,α-dimethylphenylacetamide, was obtained from Eli Lilly and Co.

added (same weight as the ketone). Raney Ni was added (20–30% of the weight of amine), and the mixture was shaken in the presence of H_2 (70.3 kg/cm²) at room temperature until the theoretical amount of H_2 was absorbed (2–18 hr). The amines are described in Table III.

Amines by Reduction of Amides with Diborane. Method F.—The reduction was effected according to the procedure of Brown and Heim[16] except that the reaction mixture was heated under reflux for 18 hr. The amines are described in Table III.

Action of $LiAlH_4$ on 2-Diethylaminoisobutyronitrile.—A solution of 63 g (0.45 mole) of the nitrile in Et_2O (600 ml) was added to a stirred solution of 30 g (0.79 mole) of $LiAlH_4$ in an ice bath at such a rate that the temperature remained below 10°. The reaction mixture was decomposed with NaOH solution. The product was a colorless oil, bp 107–109° (760 mm), $n^{25}D$ 1.4044. The yield of diethylisopropylamine was 37 g (72%). Recorded physical constants for diethylisopropylamine are bp 107.5°, $n^{25}D$ 1.4047.[17]

Reduction of the nitrile with diborane also gave only diethylisopropylamine.

Similar results were obtained when the reduction was carried out in the manner of method E using Rh–C as the catalyst.

Diethylamino-*t*-butylamine.—The reaction of 43.8 g (0.6 mole) of Et_2NH with 21.3 g (0.3 mole) of 2,2-dimethylaziridine in the presence of 60 g (0.45 mole) of anhydrous $AlCl_3$ in 100 ml of PhH was effected in the manner described by Coleman and Callen[18] for the reaction between Bu_2NH and aziridine. The yield of colorless oil, bp 155–156° (760 mm), $n^{25}D$ 1.4298, was 8.6 g (20%). It proved to be identical in all respects with the material obtained by reduction of 1-diethylamino-2-methyl-2-nitropropane.[19] The absence of the isomer, 2-diethylaminoisobutylamine, was shown by tlc.

Acknowledgments.—The microanalyses were provided by Mr. Orville Kolsto and Mr. Victor Rauschel and staff of the Abbott Microanalytical Laboratory. The pressure reactions were carried out by Mr. Morris Freifelder and Mr. Daniel Dunnigan. The pharmacological activity of these compounds was investigated by Dr. Hollis Schoepke, Dr. Thomas Darby, and Mr. Leo Wiemeler of the Abbott Pharmacology Department. We are grateful to them for permission to use their data.

(16) H. C. Brown and P. Heim, *J. Am. Chem. Soc.*, **86**, 3566 (1964).
(17) R. A. Robinson, *J. Org. Chem.*, **16**, 1911 (1951).
(18) G. H. Coleman and J. E. Callen, *J. Am. Chem. Soc.*, **68**, 2006 (1946).
(19) M. Freifelder and Y. H. Ng, *J. Org. Chem.*, **30**, 4370 (1965).