SYNTHESIS, CHARACTERIZATION AND BIOLOGICAL ACTIVITY OF DIMETHYLTIN DICARBOXYLATES CONTAINING GERMANIUM

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Abstract

A series of diorganotin dicarboxylates of the general formula $(CH_3)_2Sn(OCOCHR^3CHR^2GeR^1)_2$ where $R^1 = (C_6H_5)_3$, $(p\text{-}CH_3C_6H_4)_3$, $N(CH_2CH_2O)_3$, $R^2 = C_6H_5$, H, CH_3, $p\text{-}CH_3OC_6H_4$, $p\text{-}ClC_6H_4$, $p\text{-}CH_3C_6H_4$, $R^3 = CH_3$ and H, have been synthesized by the reaction of dimethyltin oxide with germanium substituted propionic acid in 1:2 molar ratio in toluene. The H_2O formed was removed azeotropically using a Dean and Stark apparatus. All the compounds have been characterized by IR, multinuclear (^1H, ^{13}C, ^{119}Sn) NMR, mass and Mössbauer spectroscopies. All compounds were found to have potential activity against bacteria.

Introduction

Organotin chemistry has been the subject of much interest in recent years. The importance of this area of main group organometallic chemistry is in part a result of their various industrial and agricultural applications. In addition, they have been reported as having potential antitumor activities. These are well cited in the literature [1-5]. For example, organotin carboxylates have been reported by Gielen *et. al* to have promising activity against various antitumour cells [5]. Furthermore, Crowe *et. al* stated that the R_2Sn^{2+} moiety is the active portion of the diorganotin, R_2SnXY, molecules. The function of the XY groups in these compounds is to transport the potentially active R_2Sn^{2+} moiety to the site of action where it is released by hydrolysis [4].

There has been considerable interest in recent years in the chemistry of bioactive germanium compounds. The first organogermanium pharmaceutical propagermanium was launched in Japan in 1994. Its biological activity spectrum modules the protection against viruses, immunostimulation and hepatoprolation [6-10]. In the present work, we are reporting the synthesis of several germatranyl and triaryl germyl substituted propionic acids and their reactions with dimethyltin oxide. Compound I was found to be more active for *Bacillus cerus* and *Klebslella pneumoniae* than the reference drugs.

EXPERIMENTAL

Synthesis of Compounds

Germanium-substituted propionic acids were prepared according to the literature [11] using Scheme 1. The germanium-substituted dimethyltin dipropionates were then synthesized by the condensation of dimethyltin oxide and germanium substituted propionic acids in a 1:2 molar ratio in toluene/ethanol (3:1). The general reaction is shown as follows:

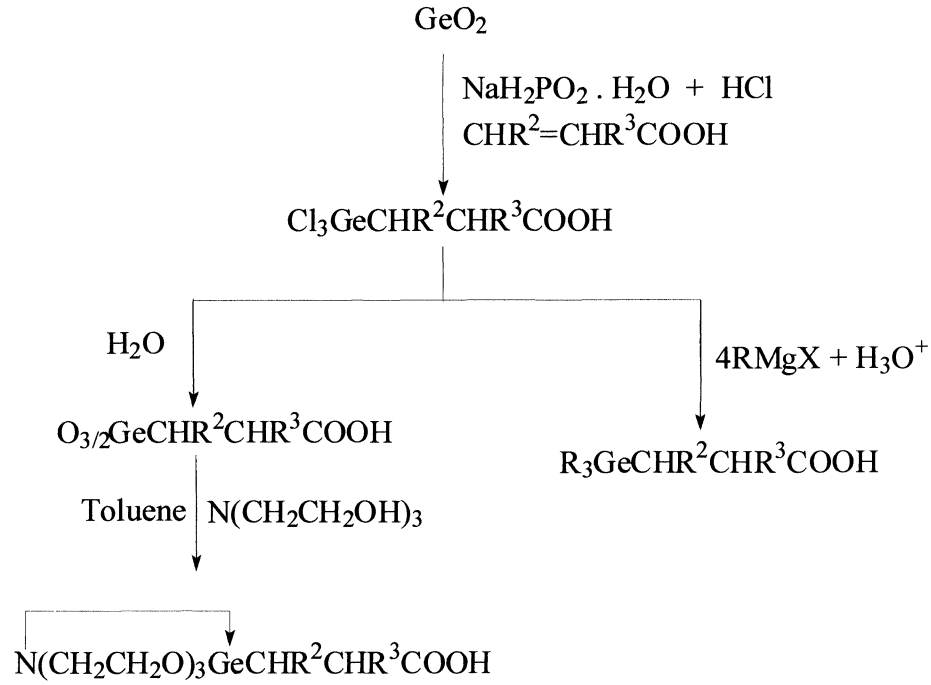
$$Me_2SnO + 2HO_2CCHR^3CHR^2GeR^1 \longrightarrow Me_2Sn[OCOCHR^3CHR^2GeR^1]_2 + H_2O$$

The following is a typical procedure for the synthesis of the dimethyltin germanium substituted carboxylates: 0.005 Mole of dimethyltin oxide and 0.01 moles of appropriate germanium substituted propionic acids were suspended in a ethanol:toluene mixture (1:3) and refluxed for 10 hours. The water formed during the reaction was removed by a Dean and Stark apparatus. The solvent was removed under vacuum and the solid thus obtained was recrystallized from a chloroform:petroleum ether mixture (1:1). The yields and physical data are listed in Table 1.

Spectra

The infrared spectra were recorded as KBr discs on a Hitachi model 270-1117 spectrophotometer. PMR spectra were recorded in $CDCl_3$ on a Bruker SF 300 or SF 400 spectrometer using TMS as the internal reference. A Jeol FX90Q instrument using Me_4Sn as the external reference was used to record the ^{119}Sn NMR. The mass spectral data were measured on a JMS-DX 300 mass spectrometer. The Mössbauer spectra were measured at 80K on a Ranger Model MS-900 Mössbauer spectrometer in the acceleration mode with a moving source geometry using a liquid nitrogen cryostat. The samples were mounted in Teflon holders. The source was 5 mCi

$Ca^{119m}SnO_3$, and the velocity was calibrated at ambient temperature using a composition of $BaSnO_3$ and Sn foil (splitting – 2.52 mm s^{-1}). The resultant spectra were analyzed by a least-square fit to Lorenzian shaped lines.



Scheme 1.

Antibacterial activity

The agar well diffusion technique was adopted for determining the antibacterial activity of the test compounds. Two mg/mL of the test solution were added to their respective wells. Other wells supplemented with DMSO and reference antibacterial drugs were used as negative and positive controls, respectively. The bacterial inocula (2-8 hours old) containing *ca.* 10^4–10^6 colony forming units (CFU)/mL were then spread on the surface of the nutrient agar plates using a sterile cotton swab. The plates were incubated immediately at 37°C for 14-19 hours. After the incubation period, the zones of inhibition were calculated.

Results and Discussion

Infrared spectra

The infrared spectra of the compounds have been recorded in the range of 4000-400 cm^{-1} and the absorptions of interest are reported in Table 2. These absorptions include the OCO, Sn–C, Sn–O, Ge–O and Ge←N vibrations. The medium to weak bands in the region 430-470 cm^{-1} are assigned to the Sn–O vibrations whereas absorptions in the region 500-630 cm^{-1} indicates the presence of the Sn–C bonds [12,13]. The Ge–O bond absorbs in the region around 898 cm^{-1} and the Ge←N coordination is found in the region of 680-695 cm^{-1} in germatrane derivatives.

It has been reported that the shifting of the ν_{asym}(COO) vibration to a lower frequency coupled with the shifting of the ν_{sym}(COO) vibration to a higher frequency for the carboxylate group when compared to the ionic carboxylate values is indicative of a bidentate carboxylate group. For unidentate coordination of the carboxylate group the reverse is true [14]. Thus, the mode of coordination of the carboxylate group has been related to the magnitude of the separation ($\Delta\nu$) of the ν_{asym}(COO) and ν_{sym}(COO) vibrations [14]. In compounds (I-X), the $\Delta\nu$ values in the solid are between 170-202 cm^{-1}. This range of $\Delta\nu$ values is indicative of carboxylate groups that behave as a bidentate ligand.

The observation of both the Sn-C symmetric and asymmetric vibrations would indicate the C-Sn-C moiety is not linear. Based on these two observations the compounds are six-coordinated with non linear methyl groups in the solid state.

Mössbauer spectra

Indirect evidence for solid state structures of organotin compounds can also be derived from Mössbauer spectroscopy. In this context, the most useful parameter is the quadruple splitting (QS) for which a given range is associated with a particular coordination number and geometry at the tin atom. Mössbauer data for compounds II and III have QS values of 3.47 and 3.32 mm s^{-1}, respectively. This range of values suggests a *trans* $R_2Sn(O_2CR)_2$ structure with chelated carboxylate groups. Thus, the structures of the compounds in the solid state are hexacoordinated which is in agreement with the infrared results.

NMR spectra

The proton NMR spectral data of the complexes are given in Table 3. The observed resonances and patterns are in agreement with those expected for the titled compounds. The integrations of the spectra are in good agreement with the expected values for the protons in the complex molecules. Furthermore, the proton NMR spectra, in $CDCl_3$, of the cyclic skeleton of the simple germatranes consisted of two triplets (A_2B_2 spin system) at 2.23-2.83 ppm for the NCH_2 and 3.68-3.73 ppm for the OCH_2 protons. This pattern is the general feature for the atrane framework [15]. The relative values of the vicinal coupling constant are in the range of ^{3}JAB (6 Hz) and are consistent with the atrane framework [15].

In compounds (I-X), the methyl groups attached directly to tin atom absorbed in the range of 0.23-0.98 ppm and appears as a sharp singlet with $^2J(^{119}Sn\text{-}^1H)$ values ranging from 56 to 84 Hz. A particular advantage of methyltin derivatives is the ease with which proton spin-spin coupling constant can be determined. The coupling constants have been related to the hybridization state of the tin atom and has been reported to increase with an increase in coordination number [16]. The $^2J(^{119}Sn\text{-}^1H)$ values can be used to estimated the C-Sn-C bond angle using the equation $\theta = 0.0161 \mid {}^2J(^{119}Sn\text{-}^1H) \mid^2 - 1.32 \mid {}^2J(^{119}Sn\text{-}^1H) \mid + 133.4$ [17]. Using this criterion, the estimated bond angles for the compounds in solution range from 106° to 136°. This magnitude for the C-Sn-C bond angles has been reported in the literature for methyl compounds as being 5 or 6 coordinated [17].

The ^{13}C NMR spectral data are given in Table 4. The methyl carbon attached to tin atom absorbs in the range of 5 to 19 ppm. In the germatrane derivatives, the carbon atoms attached to the germanium atom through the OCH_2 and NCH_2 groups resonate at 56 and 51 ppm, respectively. The ^{13}C positions of the substituents on the phenyl rings are reported in parenthesis (Table 4). The CH_2 group attached to the COO group was observed to absorb at a lower field as compared to the CH group attached to the germanium atom (Table 4). Phenyl carbons absorb in the expected region and the carbonyl carbon of the COO group absorbed in the range of 170-180 ppm as was reported earlier [18-21]. The $^1J(^{119}Sn\text{-}^{13}C)$ coupling constant values ranges from 522 to 633 Hz. The recorded $^1J(^{119}Sn\text{-}^{13}C)$ coupling constant would suggest that these compounds are five or six-coordinated. For example, $Me_2Sn(OAc)_2$, a known hexacoordinated complex has a $^1J(^{119}Sn\text{-}^{13}C)$ coupling constant of 660 Hz [17]. In addition, using equation, $|^1J(^{119}Sn\text{-}^{13}C)| = 11.4\theta - 875$ [17], the C-Sn-C bond angle can be estimated which ranges 122.5° to 133.28 which would support the suggestion that these compounds are five or six-coordinated as indicated by the observed $^1J(^{119}Sn\text{-}^{13}C)$ coupling constant and the estimated bond angle also in agreement with the bond angles obtained by the $^2J(^{119}Sn\text{-}^1H)$ coupling constants in the ^{1}H NMR studies.

Listed in Table 4 are also the ^{119}Sn NMR data. The ^{119}Sn chemical shifts cover a range of approximately 6500 ppm depending upon the coordination number [22]. It is generally accepted that the compounds with different geometries about the tin atom produce shifts in moderately well defined ranges. The range is between +200 to –60 ppm for four coordinated compounds and from –90 to –330 ppm for five coordinated systems and –125 to –515ppm for hexacoordinated compounds [23]. Since compounds II, III and VIII have δ values between –300 to –500ppm, it would indicate that these compounds are either five or six-coordinated while the other compounds are five-coordinated since their δ values lie in the range of –100 to –200ppm. These results are consistent with the ^{1}H and ^{13}C nmr results.

Table 1. Physical data and elemental analysis for $(CH_3)_2Sn(OCOCHR^3CHR^2GeR^1)_2$

No	R^1	R^2	R^3	M.p. (°C)	Yield (%)	Elemental analysis: Found (Calculated)		
						C%	H%	N%
I	C_6H_5	C_6H_5	H	160-162	75	63.58 (63.88)	4.80 (4.94)	–
II	C_6H_5	H	H	132-133	68	58.32 (58.67)	4.65 (4.88)	–
III	C_6H_5	H	CH_3	144-146	73	59.19 (59.49)	4.98 (5.17)	–
IV	C_6H_5	CH_3	H	98-100	66	59.19 (59.49)	5.07 (5.17)	–
V	p-$CH_3C_6H_4$	C_6H_5	H	196-198	60	65.15 (65.50)	5.40 (5.63)	–
VI	p-$CH_3C_6H_4$	p-$OCH_3C_6H_4$	H	216-218	60	63.98 (64.22)	5.38 (5.68)	–
VII	$N(CH_2CH_2)_3N$	p-ClC_6H_4	H	138-140	59	40.02 (40.38)	4.45 (4.62)	2.89 (2.94)
VIII	$N(CH_2CH_2)_3N$	C_6H_5	H	148-150	74	43.39 (43.54)	4.95 (5.21)	3.07 (3.17)
IX	$N(CH_2CH_2)_3N$	p-$CH_3C_6H_4$	H	140-142	60	44.65 (44.87)	5.19 (5.49)	2.99 (3.07)
X	$N(CH_2CH_2)_3N$	CH_3	H	183.185	57	34.65 (34.83)	5.46 (5.54)	3.65 (3.69)

Table 2. Selected infrared vibrations in cm^{-1} for the $(CH_3)_2Sn(OCOCHR^3CHR^2GeR^1)_2$.

No.	ν(COO)Asym.	ν(COO) Sym.	Δν	ν(Ge-O)	ν(Ge←-N)	ν(Sn-C)	ν(Sn-O)
I	1596	1398	198	—	—	615, 519	457
II	1576	1374	202	—	—	614, 541	461
III	1570	1378	192	—	—	619, 560	456
IV	1562	1377	185	—	—	615, 545	459
V	1560	1390	170	—	—	638, 544	459
VI	1598	1396	202		—	614, 529	490
VII	1561	1383	178	896, 796	692	614, 547	488
VIII	1559	1366	193	897, 790	695	618, 543	444
IX	1550	1364	186	898, 820	684	615, 531	424
X	1579	1377	202	893, 777	680	608, 534	442

Mass spectra

Main fragment ions observed in the mass spectra of compounds (I-X) are listed in Table 5. The germatranyl substituted compounds have a base peak at 220 which is due to the $N(CH_2CH_2O)_3Ge^+$ species while aryl substituted germanium compounds give base peaks fragments for Ph_3Ge^+ or $(CH_3C_6H_4)_3Ge^+$. However, the molecular ion peak was not found in any of the compounds. Also, the isotopic effects have been observed in all the fragmentation ions containing germanium and tin.

In the mass spectra of the germatrane compounds, the peak of highest intensity is at m/z 220 which corresponds to the germatranyl ion. This is a result of the cleavage of the germanium carbon bond in the parent ion. This behavior is analogous to that observed for 1-allylgermatrane and 1-fluorenyl germatrane [24] and is assumed to be a reflection of the relative strength of the germantrane skeleton.

In the mass spectral fragmentation of aryl-substituted germaniums R_3Ge (where R = C_6H_5 and $CH_3C_6H_4$), the peak of highest intensity is found at 305 and 347, respectively. The successive loss of the aryl groups takes place as given below:

$$\underset{305}{(C_6H_5)_3Ge^+} \longrightarrow \underset{228}{(C_6H_5)_2Ge^+} \longrightarrow \underset{151}{(C_6H_5)Ge^+} \longrightarrow \underset{74}{Ge^+}$$

$$\underset{347}{(CH_3C_6H_5)_3Ge^+} \longrightarrow \underset{256}{(CH_3C_6H_5)_2Ge^+} \longrightarrow \underset{165}{CH_3C_6H_5Ge^+} \longrightarrow \underset{74}{Ge^+}$$

Table 3. ^{1}H NMR data of dimethyltin carboxylate, $(CH_3)_2Sn(OCOCHR^3CHR^2GeR^1)_2$

No.	Methyl	R^2	CHR^2	CHR^3	R^1	R^3
I	0.92(s) [62.0]	6.89-7.07(m)	2.94(d) (4.7)	3.73(t) (4.7)	7.23-7.36(m)	–
II	0.96(s) [64.0]	–	1.81(t) (9.5)	2.48(t) (9.0)	7.32-7.48(m)	–
III	0.88(s) [56.0]	–	2.1(m)	2.8(m)	7.23-7.50(m)	1.18 (d) (6.5)
IV	0.98(s) [67.4]	1.2(d) (6.2)	2.39(m)	2.73(m)	7.23-7.50(m)	–
V	0.23(s) [63.0]	6.89-7.1(m)	2.66(m)	3.55(m)	7.06-7.23(m) 2.31(s)	–
VI	0.33(s) [83.5]	6.65(d) (8) 6.82(d) (8.6) 3.71(s)	2.88(m)	3.50(m) (5.4)	7.06-7.2(m) 2.3(s)	–
VII	0.67(s) [76.0]	7.15(d) 7.19(d)	2.89(m)	3.89(m)	2.74(t) (5.5) 3.68(t) (5.4)	–
VIII	0.42(s) [81.2]	7.17-7.29(m)	2.92(m)	3.89(m)	2.73(t) (5.3) 3.68(t) (5.5)	–
IX	0.60(s) [80.0]	6.97(d) (7.6) 7.21(d) (7.6) 2.23(s)	2.92(m)	3.85(m)	2.73(t) (5.5) 3.68(t) (5.5)	–
X	0.75(s) [80.0]	1.29(d) (6.7)	2.48(m)	2.75(m)	2.83(t) (5.7) 3.73(t) (5.7)	–

[ ] = $^{2}J[^{119}Sn - ^{1}H]$, ( ) = $^{3}J(^{1}H, ^{1}H)$, s = singlet, d = doublet, t = triplet, m = multiple

Thus, the mass spectra data supports the proposed structures of the compounds. Furthermore, the absence of observing fragmentation ions larger than for the molecular ions indicate that the molecules are monomeric. This observation supports the earlier IR and Mössbauer results.

Antibacterial Activity

The bactericide study results using compounds I – V as the toxicant are given in Table 6. In general, most of the compounds had similar activity to the various bacteria as the two reference drugs, Amoxicillin and Ampicillin. However in a few cases, the activities of the compounds were slightly higher than those observed for the reference drugs. For example, compound I was found to be more active for *Bacillus cerus* and *Klebslella pneumoniae* than the reference drugs. All compounds have shown good activity against all pesto bacteria.

Table 4. ^{13}C and ^{119}Sn NMR data of the dimethyltin carboxylate, $(CH_3)_2Sn(OCOCHR^3CHR^2GeR^1)_2$

No.	I	II	III	IV	V	VI	VII	VIII	IX	X
SnMe	6.3 [535]	5.1 [522]	6.3 [633]	13.0[548]	8.8 [568]	3.9 [555]	14.9 [539]	19.5 [588]	14.9 [540]	17.6 [560]
CHR^2	31.8	9.1	20.4	18.4	30.2	36.9	37.1	24.0	37.1	23.6
CHR^3	36.6	29.5	35.5	38.1	32.6	31.8	37.2	42.0	37.5	35.5
C=O	179.3	183.0	179.0	180.0	180.8	183.3	173.2	178.3	173.3	176.4
GeR^1	140.9 134.7 128.2 129.0	135.9 134.8 129.1 128.3	136.3 134.6 127.9 128.7	135.8 135.7 128.8 129.5	141.5 138.4 127.6 124.8 21.1	138.8 135.4 131.0 128.0 21.4	51.4 56.8	56.1 61.7	51.4 56.8	50.8 56.1
R^3	–	–	18.4	–	–	–	–	–	–	–
R^2	135.0 129.0 125.0 128.0	–	–	16.6	135.2 131.5 128.1 128.6	133.2 129.0 157.6 113.5 31.0	129.4 130.9 131.0 143.0	134.5 133.5 129.9 131.9	134.5 133.5 129.9 131.9	19.4
^{119}Sn	-117	-484	-544	-123	-189	-165	-118	-312	-128	-189

For ^{13}C , $CDCl_3$ at 298 K(40%) ,$CDCl_3$ for ^{119}Sn

The mechanisms involve in the bactericidal effect of these compounds have not been discerned. However, the site of action of the reference antibiotics is the cell wall. Bacteria used in this study were both gram negative and gram positive. It is well established that antibiotics that influence cell wall synthesis do not destroy gram negative bacteria. Thus, it would be of interest to investigate the effects of the dimethyltin dicarboxylates on both gram positive and gram negative bacteria. If there is a propensity of these compounds to effect the destruction of gram negative or antibiotic resistant bacteria that are unaffected by most antibiotics, then the possible use of these compounds in treating diseases caused by gram negative bacteria should be examined.

Table 5. Mass Fragmentation of selected compounds.

Fragmentation	m/z	Fragmentation	m/z
$N(CH_2CH_2O)_3GeCHPhCH_2CO_2Sn^+Me_2$	518	$(Ph_3GeCHPhCH_2CO_2)_2SnMe$	1041
$PhCH{=}CHCOOSn^+Me_2$	297	Ph_3Ge^+	305
$N(CH_2CH_2O)_3GeCHPhCH_2CO_2^+$	368	Ph_2Ge^+	228
$PhCH{=}CHCOOSn^+$	267	$PhCH{=}CHCOOSn^+$	267
$N(CH_2CH_2O)_3Ge^+$	220		227
$PhCH{=}CHCOO^+$	177	$PhGe^+$	151
Me_2Sn^+	150	Me_2Sn^+	150
$MeSn^+$	135	$MeSn^+$	135
Sn^+	120	HSn^+	121
$PhCH{=}CH^+$	103	$PhCH{=}CH^+$	103

Table 6. Bactericidal data of some selected dimethyltin derivatives.

Name of Bacteria	Clinical Implication	Zone Inhibition (mm) I	II	III	IV	V	Ref. Drug (a)	(b)
Bacillus cerus	Food poisoning	11.5	8.5	9	8.5	9.5	8	9
Corynebacterian dipheriae	Diphtheria, infections of ear, nose, throat & skin	11.5	9	9	7.5	9.5	16	14
E.coli	Infection of wounds & urinary treat & dysentery	10	7.5	—	7	7	10.5	10
Klebslella pneumoniae	Septicemia, infection of respiratory tract	10	7.5	6	7	6.5	8.0	8.5
Proteus mirabill	Infection of urinary tract, septicemia	10	8	7	7	9.5	11.0	11.5
Pseudomonas aeroginosa	Infection of wounds, eyes, septicemia	—	10	7.5	—	—	8.0	8.5
Salmonella typhi	Typhoid fever, food poisoning, localized infection	—	7	—	—	—	8.0	8.0
Shigella boydil	Inflammation of GIT, bacterial dysentery	7.5	9.5	7.5	6	6	18	19
Staphylococeus aureus	Food poisoning, scaled skin syndrome, endocarditis	7.5	7.5	7.5	7.5	7.5	14	16
Streptococeus pyogenes	Actrile rheamatic fever, scarlet fever, septic sounds	8	9.5	7.5	7.5	—	†11	9

Key: – No activity.
† Decreased in bacterial population/unit area.
Colony forming unit (CFU) ml = 10^4-10^6.
Size of well = 5mm (radius).
Ref. drug(a) = Amoxicillin $(H_2O)_3$.
Ref. drug(b) = Ampicillin $(H_2O)_3$
a=(*Invitro*) (agar well diffusion protocol) conc. 100µg/100µl of DMSO

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