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Organotin(IV) 4-methoxyphenylethanoates: Synthesis, spectroscopic characterization, X-ray structures and *in vitro* anticancer activity against human prostate cell lines (PC-3)

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ABSTRACT

A series of organotin(IV) carboxylates, $[Bu_2SnL_2]$ **(1)**, $[Et_2SnL_2]$ **(2)**, $[Me_2SnL_2]$ **(3)**, $[Bu_3SnL]_n$ **(4)**, $[Me_6Sn_2L_2]_n$ **(5)**, $[Ph_3SnL]_n$ **(6)** and $[Oct_2SnL_2]$ **(7)**, where $L = O_2CCH_2C_6H_4OCH_3$-4, have been synthesized. These complexes have been characterized by elemental analysis, FT-IR and multinuclear NMR (^1H, ^{13}C and ^{119}Sn). Based on spectroscopic results, the ligand appeared to coordinate to the Sn atom through COO moiety. Single crystal analysis has shown a bridging behavior of ligand in tributyl- and trimethyltin(IV) derivatives, and a chelating bidentate mode in diethyltin(IV) complex. Bioassay results have shown that these compounds have good antibacterial, antifungal and antitumor activity. The activity against prostate cancer cell lines (PC-3) decreased in the order **1** > **5** > **2** > **3** > **7**.

1. Introduction

The chemical properties, biological significance, industrial importance and structural characterization of organotin(IV) complexes are well documented. They have a broad spectrum of applications, being used in antifouling paints [1–3], PVC stabilization [4], as homogeneous catalysts [5], and as ion carriers in electrochemical membranes design [6]. Among organotin(IV) complexes, organotin (IV) carboxylates show significant antifungal, antibacterial and antitumor activities [7–11] which is essentially related to the number and nature of the organic groups attached to the central Sn atom, however, the role of carboxylate ligand cannot be ignored [9]. Usually triorganotin(IV) compounds display a higher biological activity than their di- and monoorganotin(IV) analogues, which has been related to their ability to bind to proteins [12–14]. In addition to their biological activities, the organotin(IV) carboxylates also present an interesting structural diversity. Depending on the mode of attachment of the carboxylate group, the resultant triorganotin(IV) complex can either be four- or five-coordinated. A tetrahedral complex results when the carboxylate group acts as a monodentate ligand [15]. For a bridged carboxylate group, a pentacoordinated polymer usually results while a chelated monomeric compound is formed when the carboxylate ligand acts as a nonbridging bidentate ligand [15]. Generally, triorganotin(IV) carboxylates with bulky R groups attached to the Sn atom will favor tetrahedral monomeric structures, while sterically less demanding R groups would favor bridged polymeric structures [16]. Among diorganotin(IV) bis(carboxylates) the coordination geometry around the Sn atom is usually found to be skew trapezoidal [17]. In such type of structural motif the Sn atom is hexa-coordinated and carboxylate ligands chelate the Sn atom, forming disparate Sn–O bond distances. In continuation of our previous work [18], we report here synthesis, spectroscopic characterization of organotin(IV) 4-methoxyphenylethanoates and their antibacterial, antifungal, cytotoxicity and antitumor activity against human prostate cell lines (PC-3).

2. Experimental

All the diorganotin(IV) and triorganotin(IV) precursors were purchased from Aldrich and were used without further purification. All the solvents were dried according to reported procedures [19]. The melting points were recorded on an electrothermal melting point apparatus, model MP-D mitamura Riken Kogyo (Japan). Microanalysis was done using a Leco CHNS 932 apparatus. IR spectra were recorded using KBr pellets in the range from 4000 to 400 cm^{-1} using a bio-Rad Excaliber FT-IR, model FTS 300 MX spectrometer (USA). ^1H and ^{13}C NMR spectra were recorded at room temperature in $CDCl_3$ on a Bruker Advance Digital 300 MHz NMR

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spectrometer (Switzerland) and a Varian Unity 500-MHz instrument [^{119}Sn; $SnMe_4$(ext) ref].

2.1. Synthesis

2.1.1. Synthesis of sodium 4-methoxyphenylethanoate

The sodium salt of ligand, R′COONa, was prepared by dropwise addition of an equimolar amount of sodium hydrogen carbonate dissolved in distilled water to a methanolic solution of ligand acid (R′COOH). The solution was stirred for 2 h at room temperature and was evaporated under reduced pressure to give a white solid which was vacuum dried.

2.1.2. Dibutyltin(IV) bis(4-methoxyphenylethanoate) (**1**)

The sodium salt R′COONa (0.94 g, 5 mmol), was refluxed for 10 h with dibutyltin(IV) dichloride (0.76 g, 2.5 mmol) in dry toluene contained in a 250 ml two necked round bottom flask. A turbid solution obtained, was left overnight at room temperature. The sodium chloride formed was filtered off and the filtrate was rotary evaporated. The resultant solid mass was recrystallized from chloroform and *n*-hexane (4:1) mixture (Yield: 1.11 g, 79%). M.p. 69–72 °C. *Anal. Calc.* for $C_{26}H_{36}O_6Sn$: C, 55.32; H, 6.38. Found: C, 55.29; H, 6.41%. IR (cm^{-1}): 1542 $\nu(OCO)_{asym}$, 1427 $\nu(OCO)_{sym}$, 532 ν(Sn–C), 465 ν(Sn–O).^{1}H NMR ($CDCl_3$, ppm): 3.62 (s, H_2, 4 H), 7.23 (d, $H_{4,4'}$, 4H), 6.87(d, $H_{5,5'}$, 4H), 3.80 (s, H_7, 6H), 1.50–1.64 (m, $H_{\alpha,\beta}$, 8H), 1.24–1.34 (m, H_γ, 4H), 0.83 (t, H_δ, 6H). ^{13}C NMR ($CDCl_3$, ppm): 182.2 (C-1), 40.2 (C-2), 126.5 (C-3), 130.2 (C-4,4′), 114.0 (C-5,5′), 158.6 (C-6), 55.3 (C-7), 25 [C-α, $^1J(^{119}Sn–^{13}C)$ = 790 Hz], 26.5 [C-β, $^2J(^{119}Sn–^{13}C)$ = 38 Hz], 26.2 [C-γ, $^3J(^{119}Sn–^{13}C)$ = 98 Hz], 13.5 (C-δ). ^{119}Sn NMR ($CDCl_3$, ppm): −240.1.

2.1.3. Diethyltin(IV) bis(4-methoxyphenylethanoate) (**2**)

Compound **2** was prepared and was recrystallized in the same way as **1**. (Yield: 2.18 g, 86%). M.p. 98 °C. *Anal.* Calc. for $C_{22}H_{28}O_6Sn$: C, 51.97; H, 5.51. Found: C, 51.95; H, 5.53%. IR (cm^{-1}): 1510 $\nu(OCO)_{asym}$, 1377 $\nu(OCO)_{sym}$, 505 ν(Sn–C), 484 ν(Sn–O). ^{1}H NMR ($CDCl_3$, ppm): 3.64 (s, H_2, 4H), 7.23 (d, $H_{4,4'}$, 4H), 6.87 (d, $H_{5,5'}$, 4 H), 3.81 (s, H_7, 6 H), 1.61 (q, H_α, 4H), 1.22 (t, H_β, 6H). ^{13}C NMR ($CDCl_3$, ppm): 182.3 (C-1), 40.1 (C-2), 126.5 (C-3), 130.2 (C-4,4′), 114.0 (C-5,5′), 158.6 (C-6), 55.2 (C-7), 17.3 [C-α, $^1J(^{119/117}Sn–^{13}C)$ = 582/562 Hz], 8.8 [C-β, $^2J(^{119}Sn–^{13}C)$ = 43.5 Hz]. ^{119}Sn NMR ($CDCl_3$, ppm): −156.8.

2.1.4. Dimethyltin(IV) bis(4-methoxyphenylethanoate) (**3**)

Compound **3** was prepared and was recrystallized in the same way as **1**. (Yield: 1.56 g, 65%). M.p. 76 °C. *Anal. Calc.* for $C_{20}H_{24}O_6Sn$: C, 50.00; H, 5.00. Found: C, 50.05; H, 4.98%. IR (cm^{-1}): 1510 $\nu(OCO)_{asym}$, 1361 $\nu(OCO)_{sym}$, 573 ν(Sn–C), 498 ν(Sn–O).^{1}H NMR ($CDCl_3$, ppm): 3.63 (s, H_2, 4H), 7.21 (d, $H_{4,4'}$, 4H), 6.88 (d, $H_{5,5'}$, 4H), 3.81(s, H_7, 6H), 0.95 [s, H_α, 6H, $^2J(^{119/117}Sn–^1H)$ = 82/79 Hz]. ^{13}C NMR ($CDCl_3$, ppm): 181.9 (C-1), 40.0 (C-2), 126.3 (C-3), 130.2 (C-4,4′), 114.0 (C-5,5′), 158.7 (C-6), 55.2 (C-7), 4.2 [C-α, $^1J(^{119}Sn–^{13}C)$ = 703 Hz]. ^{119}Sn NMR ($CDCl_3$, ppm): −237.8.

2.1.5. Tributyltin(IV) 4-methoxyphenylethanoate (**4**)

Compound **4** was prepared in the same way as **1**, using equimolar molar amounts. The product was recrystallized from chloroform and *n*-hexane (4:1) mixture. (Yield: 1.86 g, 82%). M.p. 63–64 °C. *Anal.* Calc. for $C_{21}H_{36}O_3Sn$: C, 55.26; H, 7.89. Found: C, 55.24; H, 7.91%. IR (cm^{-1}): 1577 $\nu(OCO)_{asym}$, 1377 $\nu(OCO)_{sym}$, 535 ν(Sn–C), 475 ν(Sn–O). ^{1}H NMR ($CDCl_3$, ppm): 3.57 (s, H_2, 2H), 7.22 (d, $H_{4,4'}$, 2H), 6.85 (d, $H_{5,5'}$, 2H), 3.80 (s, H_7, 3H), 1.69–1.53 (m, H_α, 6H), 1.41–1.22 (m, $H_{\beta,\gamma}$, 12H), 0.90 (t, H_δ, 9H). ^{13}C NMR ($CDCl_3$, ppm): 177.4 (C-1), 41.2 (C-2), 128.0 (C-3), 130.8 (C-4,4′), 113.8 (C-5,5′), 158.3 (C-6), 55.2 (C-7), 16.4 [C-α, $^1J(^{119/117}Sn–^{13}C)$ = 355/339 Hz], 27.8 [C-β, $^2J(^{119}Sn–^{13}C)$ = 20 Hz], 27.0 [C-γ, $^3J(^{119}Sn–^{13}C)$ = 63 Hz], 13.7 (C-δ). ^{119}Sn NMR ($CDCl_3$, ppm): 107.0.

2.1.6. Trimethyltin(IV) 4-methoxyphenylethanoate (**5**)

Compound **5** was prepared in the same way as **1**, using equimolar molar amounts. The product was recrystallized from chloroform and *n*-hexane (4:1) mixture (Yield: 1.27 g, 77%). M.p. 148–149 °C. *Anal. Calc.* for $C_{12}H_{18}O_3Sn$: C, 43.64; H, 5.45. Found: C, 43.61; H, 5.48%. IR (cm^{-1}): 1561 $\nu(OCO)_{asym}$, 1394 $\nu(OCO)_{sym}$, 546 ν(Sn–C), 472 ν(Sn–O). ^{1}H NMR ($CDCl_3$, ppm): 3.58 (s, H_2, 2H), 7.22 (d, $H_{4,4'}$, 2H), 6.87 (d, $H_{5,5'}$, 2H), 3.81 (s, H_7, 3H), 0.55 [s, H_α, 9H, $^2J(^{119/117}Sn–^1H)$ = 58/56 Hz]. ^{13}C NMR ($CDCl_3$, ppm): 177.4 (C-1), 40.9 (C-2), 127.7 (C-3), 130.2 (C-4,4′), 113.8 (C-5,5′), 158.3 (C-6), 55.2 (C-7), 2.4 [C-α, $^1J(^{119/117}Sn–^{13}C)$ = 395/377 Hz]. ^{119}Sn NMR ($CDCl_3$, ppm): −139.2.

2.1.7. Triphenyltin(IV) 4-methoxyphenylethanoate (**6**)

Compound **6** was prepared in the same way as **1**, using equimolar molar amounts. The product was recrystallized from chloroform and n-hexane (4:1) mixture (Yield: 1.91 g, 74%). M.p. 294–298 °C. *Anal.* Calc. for $C_{27}H_{24}O_3Sn$: C, 62.79; H, 4.65. Found: C, 62.75; H, 4.68%. IR (cm^{-1}): 1576 $\nu(OCO)_{asym,}$ 1392$\nu(OCO)_{sym,}$ 459 ν(Sn–O). ^{1}H NMR ($CDCl_3$, ppm): 3.71 (s, H_2, 2H), 7.22 (d, $H_{4,4'}$, 2H), 6.86 (d, $H_{5,5'}$, 2H), 3.81(s, H_7, 3H), 7.74–7.71 (m, $H_{\beta,\beta'}$, 6H), 7.47–7.45 (m, $H_{\gamma,\gamma',\delta}$, 9H). ^{13}C NMR ($CDCl_3$, ppm): 178.9 (C-1), 40.3 (C-2), 128.9 (C-3), 130.3 (C-4,4′), 113.9 (C-5,5′), 158.5 (C-6), 55.3 (C-7), 138.1 [C-α, $^1J(^{119}Sn–^{13}C)$ = 640 Hz], 136.9 [C-β, $^2J(^{119}Sn–^{13}C)$ = 48 Hz], 128.9 [C-γ, $^3J(^{119}Sn–^{13}C)$ = 63 Hz], 130.2 [C-δ, $^4J(^{119}Sn–^{13}C)$ = 13.5 Hz]. ^{119}Sn NMR ($CDCl_3$, ppm): −113.2.

2.1.8. Dioctyltin(IV) bis(4-methoxyphenylethanoate) (**7**)

The ligand acid, R′COOH (0.83 g, 5 mmol) and dioctyltin(IV) oxide (0.90 g, 2.5 mmol), were suspended in dry toluene (100 ml) in a single necked round bottom flask (250 ml), equipped with a Dean-Stark apparatus. The mixture was refluxed for 10 h and water formed during the condensation reaction was removed at regular intervals. A clear solution thus obtained, was cooled to room temperature and solvent was removed under reduced pressure. The solid obtained was recrystallized from chloroform and *n*-hexane (4:1) mixture. (Yield: 1.32 g, 78%). M.p. 90–92 °C. *Anal.* Calc. for $C_{34}H_{52}O_6Sn$: C, 60.36; H, 7.69. Found: C, 60.32; H, 7.73%. IR (cm^{-1}): 1514 $\nu(OCO)_{asym}$, 1380 $\nu(OCO)_{sym}$, 525 ν(Sn–C), 483 ν(Sn–O). ^{1}H NMR ($CDCl_3$, ppm): 3.62 (s, H_2, 4H), 7.23 (d, $H_{4,4'}$, 4H), 6.86 (d, $H_{5,5'}$, 4H), 3.80 (s, H_7, 6H), 1.58–1.55 (bs, $H_{\alpha,\beta}$, 4H), 1.28–1.22 (bs, $H_{\gamma\text{-}\gamma'}$, 28H), 0.90 (t, $H_{\delta'}$, 6H]. ^{13}C NMR ($CDCl_3$, ppm): 182.0 (C-1), 40.2 (C-2), 126.5 (C-3), 130.4 (C-4,4′), 114.0 (C-5,5′), 158.6 (C-6), 55.2 (C-7), 25.2 [C-α, $^1J(^{119/117}Sn–^{13}C)$ = 575/556 Hz], 24.3 [C-β, $^2J(^{119}Sn–^{13}C)$ = 37 Hz], 33.2 [C-γ, $^3J(^{119/117}Sn–^{13}C)$ = 95/91 Hz], 33.2 (C-δ), 29.1 (C-α′), 29.0 (C-β′), 22.7 (C-γ′), 10.5 (C-δ′). ^{119}Sn NMR ($CDCl_3$, ppm): −150.3.

2.2. X-ray crystallographic studies

The X-ray diffraction data were collected on a Bruker SMART APEX CCD diffractometer, equipped with a 4 K CCD detector. Data integration and global cell refinement was performed with the program SAINT [20]. The program suite SAINTPLUS was used for space group determination (XPREP) [20]. The structure was solved by Patterson method; extension of the model was accomplished by direct method and applied to difference structure factors using the program DIRDIF [21]. Crystal data and numerical details on data collection and refinement are given in Table 1. All refinement calculations and graphics were performed with the program packages SHELXL [22] a locally modified version of the program PLUTO and PLATON package [23,24]. The isotropic displacement parameters for

Table 1
Crystal data and structure refinement parameters for compounds **2**, **4** and **5**.

Compound	**2**	**4**	**5**
Moiety Formula	$C_{22}H_{28}O_6Sn$	$C_{21}H_{36}O_3Sn$	$C_{24}H_{36}O_6Sn_2$
Formula Weight	507.13	455.23	657.97
Crystal system	monoclinic	monoclinic	monoclinic
Space group	*C2/c*	$P2_1/c$	$P2_1/c$
Unit cell dimensions			
a (Å)	31.852	13.016(2)	6.9114(3)
b (Å)	5.297	16.8865(3)	27.6244(13)
c (Å)	13.659	10.3679(16)	14.1378(7)
β (°)	105.83	106.213(23)	93.4095(8)
V (Å^3)	2217.1	2185.4(6)	2694.5(2)
θ Ranges for data collection (°)	3.90–23.18	2.92–26.37	2.64–28.28
Z	4	4	4
ρ_{calc} (g cm^{-3})		1.389	1.622
F(000)	1032	944	1312
Crystal size (mm)	0.12 × 0.06 × 0.015	0.28 × 0.23 × 0.08	0.39 × 0.28 × 0.13
T (K)	100(1)	100(1)	100(1)
Index ranges	*h*: −31 → 33; *k*: −5 → 5; *l*: −14 → 14	*h*: −17 → 17; *k*: −22 → 22; *l*: −13 → 13	*h*: −9 → 8; *k*: −36 → 36; *l*: −18 → 18
Total data	10495	18008	23247
Unique data [R_{int}]	1414 [0.0194]	5332 [0.0341]	6656 [0.0231]
Final *R* indices [$I > /4\sigma(I)$]		R_1 = 0.0369, wR_2 = 0.0876	R_1 = 0.0244, wR_2 = 0.0589
Final *R* indices [$I > /2\sigma(I)$]	R_1 = 0.0185, wR_2 = 0.0608		

hydrogen atoms were refined on F^2 with full-matrix least-squares procedures.

3. Results and discussion

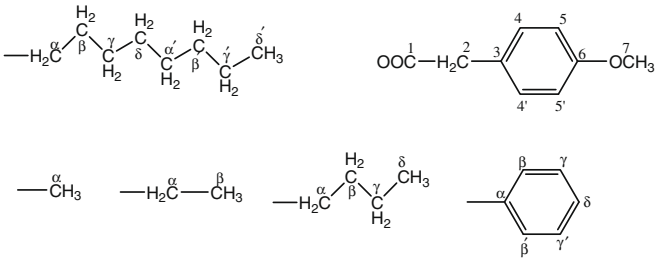
3.1. Synthesis of complexes **1–7**

Reaction of R_3SnCl/R_2SnCl_2 with NaL in 1:1/1:2 molar ratios, and that of R_2SnO with HL in 1:2 molar ratios, respectively led to the formation of complexes according to Eqs. (1)–(3), Scheme 1. The resulting complexes were obtained in good yield (65-86%). All the complexes were white solids, stable in air and were soluble in $CHCl_3$ and DMSO.

$$R_2SnCl_2 + 2NaL \rightarrow R_2SnL_2 + 2NaCl$$
$$R = n\text{-Butyl}\ (\mathbf{1}), \text{Ethyl}\ (\mathbf{2}), \text{Methyl}\ (\mathbf{3}) \quad (1)$$

$$R_3SnCl + NaL \rightarrow R_3SnL + NaCl$$
$$R = n\text{-Butyl}\ (\mathbf{4}), \text{Methyl}\ (\mathbf{5}), \text{Phenyl}\ (\mathbf{6}) \quad (2)$$

$$R_2SnO + 2HL \rightarrow R_2SnL_2 + H_2O \quad R = n\text{-Octyl}\ (\mathbf{7}) \quad (3)$$



Scheme 1.

3.2. IR spectra

The assignment of IR bands of complexes **1–7** has been made by comparison with the IR spectra of their related precursors. Appearance of new bands at 498–459 cm^{-1} and 573–505 cm^{-1} for all complexes, which are absent from the spectrum of free ligand, can be assigned to Sn–O and Sn–C stretching mode of vibrations, respectively. Of particular interest in the IR spectra is the Δv value, a difference between asymmetric and symmetric vibrations of COO moiety. According to the literature [25], Δv greater than 250 cm^{-1} shows a monodentate carboxylate moiety, a value between 150 and 250 cm^{-1} indicates a bridging behavior while a difference less than 150 cm^{-1} corresponds to a chelate structure. In our present investigation complexes **1**, **2**, **3** and **7** show a chelating behavior while **4–6** illustrate a bridging mode of coordination in solid state. These observations are further supported by the crystal structures of complexes **2**, **4** and **5**.

3.3. ^{1}H NMR spectra

The assignment of the proton resonances were made by their peak multiplicity, intensity pattern and comparison of the integration values of the protons with expected composition. A comparison of the ^{1}H NMR spectra of all organotin(IV) complexes with the ligand have shown disappearance of signal for OH (11.66 ppm) proton on the formation of Sn–O bond. Protons of alkyl/aryl groups attached to Sn atom give multifaceted pattern except for compounds **3** and **5**, where sharp singlets for CH_3 protons are observed with ^2J (^{119}Sn/^{117}Sn–^{1}H) values, 82/79 and 58/56, respectively. These ^2J (^{119}Sn–^{1}H) values correspond to C–Sn–C bond angles 133.28° and 111.1°, which confirm six and four coordinated Sn atom in solution in compound **3** and **5**, respectively [26].

3.4. ^{13}C NMR spectra

The ^{13}C NMR chemical shifts due to different R groups attached to Sn atom were observed at positions comparable to the other similar compounds [8]. In ^{13}C NMR data, the carbons attached to Sn atom in all the synthesized compounds have shown satellites due to ^nJ [^{119}Sn/^{17}Sn–^{13}C] coupling. The coupling constants are important indicators for structural elucidation of organotin(IV) carboxylates. In present study, triorganotin carboxylates (compounds **4**, **5** and **6**) exhibit ^1J (^{119}Sn–^{13}C) being of the order of 355, 395 and 640 Hz, respectively. These values confirm a monomeric tetrahedral geometry in solution for these complexes [27,28]. In complex **6**, the ^{13}C chemical shift of the *ipso*-carbon at 138 ppm further confirm the tetrahedral geometry around Sn [29]. In case of **1**, **2**, **3** and **7** ^1J [^{119}Sn–^{13}C] values and (C–Sn–C) bond angles are 790 (146.05°), 582 (127.80°), 703 (138.42°) and 575 Hz (127.21°), respectively [8]. These values suggest a decrease in coordination number of Sn from six to five for compounds **2** and **7** while compounds **1** and **3** exhibit skew-trapezoidal geometry around Sn atom in solution.

3.5. ^{119}Sn NMR spectra

The solution structure of the complexes **1–7** was further confirmed by ^{119}Sn NMR. The ^{119}Sn NMR spectra of **4–6** displayed sharp signals at 107.0, 139.2 and −113.2 ppm, respectively, which were consistent with those for similar four-coordinate organotin(IV) carboxylates [30,31]. Complexes **2** and **7** gave ^{119}Sn signal correspond to five-coordinate Sn atom [8], while six-coordinate geometry was assigned to complexes **1** and **3** on the basis of ^{119}Sn chemical shift [32].

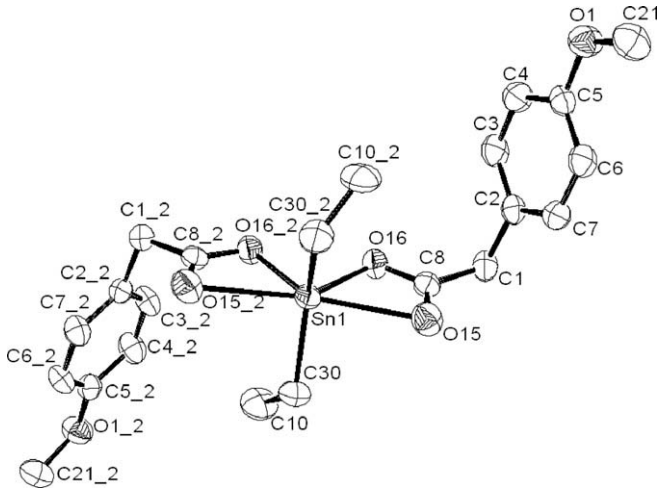


Fig. 1. ORTEP drawing of compound **2** with numbering scheme.

3.6. Crystal structure of complex *2*, *4* and *5*

The molecular structure of the complex **2** is shown in Fig. 1 whereas the crystal data, selected bond lengths and bond angles are listed in Tables 1 and 2. The geometry at the central Sn atom is skew-trapezoidal in which the basal plane is defined by four oxygen atoms derived from the two chelating carboxylate ligands whereas the remaining two positions are occupied by two ethyl substituents. The carboxylate ligands chelate the Sn center in an asymmetric way, and are reflected in two shorter Sn–O bonds and two longer Sn–O bonds. The ethyl groups do not occupy the exact axial positions as a result C–Sn–C angle is 136.96 (15)° which falls in the range (122.6–156.9°) for skew-trapezoidal geometry [33,34]. The asymmetric mode of coordination of the carboxylate ligands is further confirmed by unequal C–O bond distances; 1.248(3) Å and 1.285(3) Å. The Shorter C–O bond value is for weakly coordinated O atoms of the ligands. The Sn–C bond distances, 2.120(3) are in agreement with previous reports [35].

The molecular structure of complex **4** and **5** are shown in Figs. 2 and 4, respectively. The complexes exhibit a carboxylate-bridged motif in which the Sn center shows *trans*-R_3SnO_2 (where R = CH_3, *n*-Bu) trigonal-bipyramidal coordination, the equatorial plane being defined by the three R groups while axial positions are occupied by two oxygen atoms. According to the literature [36], the geometry around Sn atom can be characterized by the value of $\tau = (\beta - \alpha)/60$, where β is the largest of the basal angles around the Sn atom. The angle values $\alpha = \beta = 180°$ correspond to a square-pyramidal geometry, and the value of $\alpha = 120°$ corresponds to a perfect trigonal-bipyramidal geometry. Thus, the τ value is equal to zero for a perfect square-pyramidal and unity for perfect trigonal-bipyramidal. The calculated τ value for complex **4** is 0.80 whereas for **5**, two values 0.82 (Sn1) and 0.89 (Sn2), were obtained. These values indicate a highly distorted trigonal-bipyramidal arrangement around Sn atom. The distortion in complex **4** is more than **5** that may be due to bulky butyl groups attached to Sn atom. The angles of axial bonds [O–Sn–O] are 176.01°, in complex **4** and 169.73°, in complex **5** while the sum of the equatorial C–Sn–C angles are 358.02° and 359.37°, respectively. Thus, carboxylate ligand chelated to two symmetry related Sn atoms and gave rise to the unequal Sn–O bond distances. The inequality in the Sn–O bonds is reflected in the associated C–O bond distances, the longer C–O bond is involved with shorter

Table 2
Selected bond length (Å) and bond angles (°) of compound **2**.

Bond length (Å)			
Sn1–C30	2.120(3)	Sn1–O15–2	2.543(2)
Sn1–O15	2.543(2)	Sn1–O16–2	2.1140(18)
Sn1–C30–2	2.120(3)	O15–C8	1.248(3)
Sn1–O16	2.1140(18)	O16–C8	1.285(3)
Bond angles (°)			
C30–Sn1–C30–2	136.96(15)	O16–Sn1–O15–2	135.57(7)
C30–Sn1–O16	107.06(9)	O16–2–Sn1–O15–2	54.86(7)
C30–2–Sn1–O16	105.39(9)	C30–Sn1–O15	87.81(10)
C30–Sn1–O16–2	105.39(9)	C30–2–Sn1–O15	88.37(10)
C30–2–Sn1–O16–2	107.06(9)	O16–Sn1–O15	54.86(7)
O16–Sn1–O16–2	80.75(9)	O16–2–Sn1–O15	135.57(7)
C30–Sn1–O15–2	88.37(10)	O15–2–Sn1–O15	169.57(10)
C30–2–Sn1–O15–2	87.81(10)		

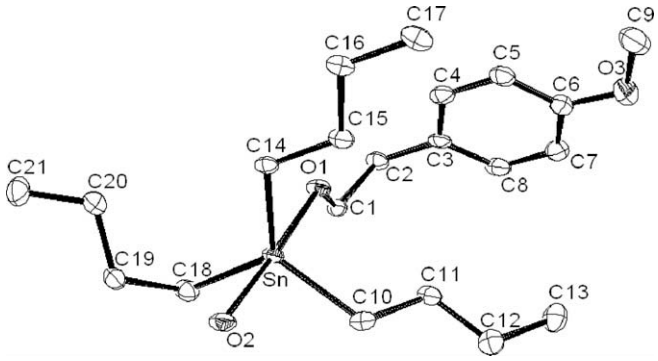


Fig. 2. ORTEP drawing of asymmetric unit of compound **4** with numbering scheme.

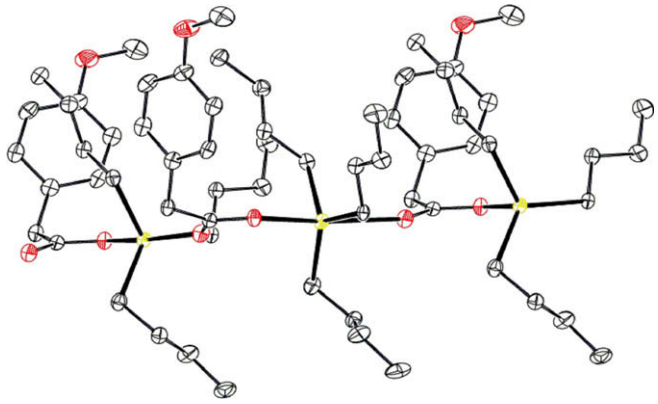


Fig. 3. The ID chain structure of compound **4**, propagation via O → Sn Coordination.

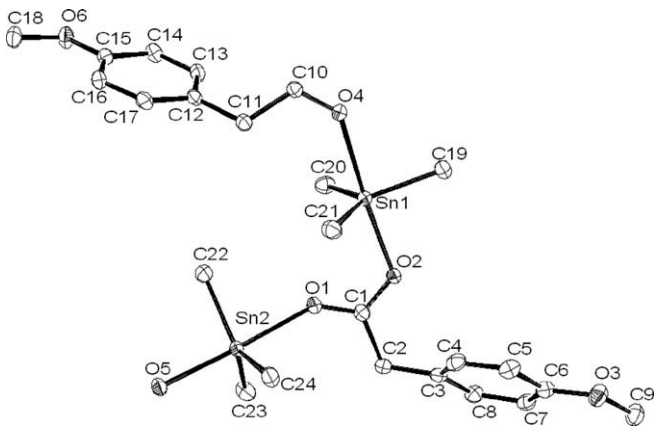


Fig. 4. ORTEP drawing of asymmetric unit of compound **5** with numbering scheme.

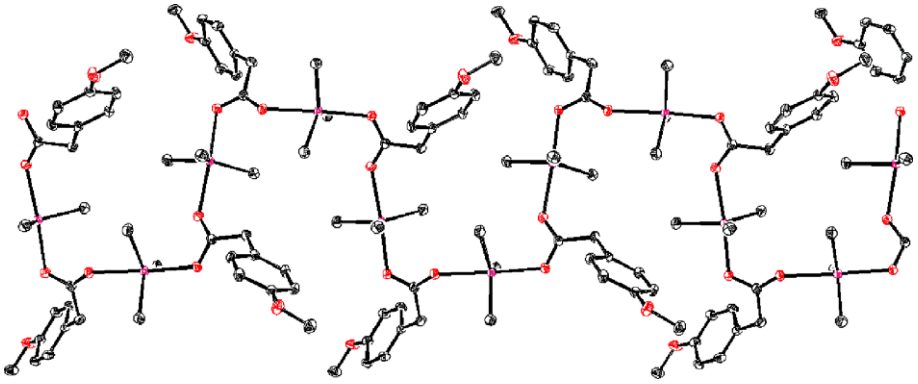


Fig. 5. The ID chain structure of compound **5**, propagation via O → Sn Coordination.

Sn–O interaction. These bond lengths are in agreement with the reported triorganotin(IV) carboxylates [37]. The intermolecular C═O → Sn coordination, in both compounds, leads to infinite zig-zag chains containing the Sn centers and carboxylate groups as shown in Figs. 3 and 5. The crystal data, selected bond lengths and bond angles are given in Tables 1, 3 and 4.

4. Biological studies

4.1. Antibacterial

The synthesized complexes were tested for their antibacterial activity, using the agar well diffusion method [38] and data are listed in Table 5. The ligand was found to be inactive against all bacteria. It was concluded that all complexes except **7** show higher activity than the acid against different bacteria but were less active than the standard drug. In present study, the diorganotin(IV) derivatives are found to be more active than the triorganotin(IV) derivatives. This situation is in sharp contrast to the earlier assessment that an increase in the number of R groups on the tin(IV) atom enhances its biological activity. This anomalous behavior can be explained on the basis of the anionic ligand group that generally plays a secondary role. In some cases however, it may also play important role to enhance the biocidal activity of organotin(IV) compounds [39].

Table 3
Selected bond length (Å) And bond angles (°) of compound **4**.

Bond length (Å)			
Sn–O1	2.4682(17)	Sn–C10	2.139(2)
Sn–O2_b	2.1778(15)	Sn–C14	2.151(3)
Sn–C18	2.146(3)	O1–C1	1.238(3)
O2–C1	1.283(3)		
Bond angles (°)			
O1–Sn–C10	83.22(7)	C10–Sn–O2_b	87.11(7)
O1–Sn–C14	85.15(8)	C14–Sn–C18	120.21(10)
O1–Sn–C18	87.47(9)	C14–Sn–O2_b	95.98(8)
O1–Sn–O2_b	169.73(6)	C18–Sn–O2_b	100.66(9)
C10–Sn–C14	115.6(1)	Sn–O1–C1	150.94(14)
C10–Sn–C18	122.21(10)		

Table 4
Selected bond length (Å) and bond angles (°) of compound **5**.

Bond length (Å)			
Sn1–O2	2.2176(14)	O2–C1	1.273(2)
Sn1–O4	2.3394(14)	Sn2 –O1	2.3318(14)
Sn1–C19	2.126(3)	Sn2–C22	2.126(3)
Sn1–C20	2.123(3)	Sn2–C23	2.127(3)
Sn1–C21	2.122(2)	Sn2–C24	2.128(3)
O1–C1	1.256(2)	Sn2–O5_b	2.2210(14)
Bond angles (°)			
O2–Sn1–O4	176.01(5)	O1–Sn2–C22	83.62(7)
O2–Sn1–C19	90.19(8)	O1–Sn2–C23	91.18(8)
O2–Sn1–C21	92.50(8)	O1–Sn2–C24	87.74(8)
O4–Sn1–C20	87.02(8)	O1–Sn2–O5_b	177.00(5)
O4–Sn1–C21	89.13(8)	C22–Sn2–C23	115.43(10)
C20–Sn1–C21	126.51(10)	C22–Sn2–C24	123.72(10)
O2–Sn1–C20	94.94(8)	C22–Sn2–O5_b	93.53(7)
O4–Sn1–C19	85.83(8)	C23–Sn2–C24	120.27(10)
C19 –Sn1–C21	115.96(10)	C23–Sn2–O5_b	90.87(8)
C19–Sn1–C20	116.9(1)	C24–Sn2–O5_b	93.12(8)

4.2. Antifungal activity

The complexes were checked for antifungal activity against different plant pathogens by using the Agar tube dilution protocol [38] and the data collected are listed in Table 6. Generally, all derivatives show markedly higher antifungal activity than the ligand with few exceptions. Triorganotin(IV) derivatives are found to be more active than the diorganotin derivatives, a behavior quite consistent with the earlier report [40].

4.3. Cytotoxicity

The complexes were also screened for cytotoxicity data, using Brine-shrimp (*Artemia salina*) bioassay lethality method [38] and results are shown in Table 7. The data illustrate that compounds **3**, **4**, **7** and ligand show no cytotoxicity. However, compounds **1**, **2**, **5** and **6** show low LD_{50} values in the range of 0.00–1.95 μg/ml and exhibited significant toxicity.

4.4. Anticancer activity

The experimental conditions for *in vitro* anticancer assay against prostate cancer cells (PC-3) of compounds **1**, **2**, **3**, **5** and **7** are already described in the literature [41] and the activity of the

Table 5
Antibacterial bioassay results[a,b] for complexes **1**–**7** (inhibition zone in mm).

Bacterium	1	2	3	4	5	6	7	Imipinem[b]
Eschericha coli	12	14	10	13	17	14		30
Bacillus subtilis	17	16	11	12	12	16		37
Shigella flexenari	13	20	16	11		20		36
Staphylococcus aureus	15	20			16	26		26
Pseudomonas aeruginosa		19	12	11	10			32
Salmonella typhi	17	20		10				30

[a] Concentration used: 1 mg/ml of DMSO, Size of well: 6 mm (diameter).
[b] Standard drug, dash indicate inactivity.

Table 6
Antifungal bioassay results [a,b,c] for complexes **1**–**7**.

Fungus	Inhibition (%)							Standard drugs	MIC (μg/ml)
	1	**2**	**3**	**4**	**5**	**6**	**7**		
Candida albicans			10	80	80	90		Miconazole	110.8
Aspergillus flavus	20	80	20	70	90	60		AmphotericinB	20
Microsporum canis	30		40	50	90	70		Miconazole	98.25
Fusarium solani	40		10	60	70	80		Miconazole	73.25
Candida glabrata			30	90	80	60		Miconazole	110.8

[a] Concentration of sample = 400 μg/ml of DMSO.
[b] Incubation period = 7 days.
[c] Incubation temperature = 27 °C.

Table 7
Cytotoxicity data[a,b] of compounds **1**–**7**.

Compound number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
LD_{50} (μg/ml)	1.95	0.74			0.42	0.67	

[a] Against brine-shrimps (*in vitro*).
[b] Standard drug Etoposide LD_{50} 7.46 μg/ml.

Table 8
In vitro anticancer results (IC_{50}, μg/ml) of compounds **1**, **2**, **3**, **5** and **7**.

Compound number	PC-3
1	2.53 ± 0.94
2	5.30 ± 0.88
3	32.92 ± 1.21
5	4.21 ± 0.32
7	>100
[a]Doxorubicin	0.912

[a] Standard drug used.

compounds is presented in Table 8. The activity of the compounds decreased in the order **1** > **5** > **2** > **3** > **7**. These compounds exhibited lower anticancer activity than standard drug, doxorubicin. However, compound **1** was found to be the most active, a behavior normally shown by the dibutyltin(IV) bis(carboxylate) [42].

5. Conclusion

This contribution has shown that combination of di- and triorganotin(IV) moieties with 4-methoxyphenylethanoic acid result in the formation of polymeric or discrete complexes. These complexes exhibited different structural chemistry in solution and solid state. Some of these complexes have been found to be active against different strains of bacteria and fungi, their activity against human prostate cell lines (PC-3) decrease in the order **1** > **5** > **2** > **3** > **7**.

Acknowledgment

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Appendix A. Supplementary material

CCDC 688235, 688094 and 688093 contain the supplementary crystallographic data for **2**, **4** and **5**. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif. Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ica.2009.01.003.

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