

AD _____

Award Number: DAMD17-01-1-0830

TITLE: Selective Cytotoxic Phospholipids for Prostate Cancer

PRINCIPAL INVESTIGATOR: Duane D. Miller, Ph.D.

CONTRACTING ORGANIZATION: The University of Tennessee
Memphis, TN 38163

REPORT DATE: October 2004

TYPE OF REPORT: Annual

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release;
Distribution Unlimited

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

20050408 043

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE October 2004	3. REPORT TYPE AND DATES COVERED Annual (20 Sep 2003 - 19 Sep 2004)	
4. TITLE AND SUBTITLE Selective Cytotoxic Phospholipids for Prostate Cancer			5. FUNDING NUMBERS DAMD17-01-1-0830	
6. AUTHOR(S) Duane D. Miller, Ph.D.			8. PERFORMING ORGANIZATION REPORT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) The University of Tennessee Memphis, TN 38163 E-Mail: wilkie.wilson@duke.edu				
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Materiel Command Fort Detrick, Maryland 21702-5012			10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES Original contains color plates: ALL DTIC reproductions will be in black and white				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited				12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 Words) The goal of this project is to build upon our discovery of two phospholipid lead compounds, serine amide phosphate (SAP) and serine diamide phosphate (SDAP), that have been shown to be selective in their cytotoxic actions in PC-3 and DU-145 prostate cancer cells respectively. These agents were originally designed as part of a series of compounds to inhibit lysophosphatidic acid (LPA), a phospholipid growth factor. After discovering the antiproliferation activity of SAP and SDAP in prostate cancer cell lines we propose to synthesize a focused set of SAP and SDAP analogs. We have found that the synthesis of these compounds can be prepared in a shorter sequence and in better yield using our new synthetic scheme. We have tested for the affinity of the synthesized compounds in PC-3, DU-145, and LNCaP cell lines as we proposed earlier. In addition to these cell lines we have also tested for affinity of these compounds in two additional PPC-1 and TSU cell lines (data shown in Table 1). These new analogs have provided valuable insight as to the importance of chirality, lipid solubility, spatial orientation, and important functional groups of the pharmacophore and for the optimization of the antiproliferative actions of this new set of drugs. Our most recent compounds are based on the thiazolidinones (2) and the thiazolidine (3) analogs. We have utilized new synthetic schemes for these new compounds and have found the optimum length of the aliphatic chain in these two series. In earlier studies it appeared in our Serine Amide Phosphate (SAP) series that the aliphatic chain is optimum at C-14 while with the new compounds it appears to be C-18 on DU-145 and PC-3 cell lines. In a few instances we have discovered a new set of 2-arylthiazolidine-4-carboxylic acid amides that show sub micromolar anticancer activity in the cell lines described above. We have designated this set of compounds as 2-arylthiazolidine-4-carboxylic acid amides (ATCAAs). This report shares the critical structure activity relationships for optimum activity in prostate cancer cells.				
14. SUBJECT TERMS -arylthiazolidine-4-carboxylic acid amides, cytotoxic, chirality, pharmacophore, lipid solubility, synthesis,				15. NUMBER OF PAGES 68
				16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

Table of Contents

Cover.....	1
SF 298.....	2
Table of Contents.....	3
Introduction.....	4
Body.....	5
Key Research Accomplishments.....	10
Reportable Outcomes.....	11
Conclusions.....	11
References.....	none
Appendices.....	12

Introduction The goal of this project is to build upon our discovery of two phospholipid lead compounds, serine amide phosphate (**SAP**) and serine diamide phosphate (**SDAP**), that have been shown to be selective in their cytotoxic actions in PC-3 and DU-145 prostate cancer cells respectively. These agents were originally designed as part of a series of compounds to inhibit lysophosphatidic acid (LPA), a phospholipid growth factor. After discovering the antiproliferation activity of SAP and SDAP in prostate cancer cell lines we propose to synthesize a focused set of SAP and SDAP analogs using the combinatorial parallel-compound solution phase syntheses when appropriate, and to prepare the remaining analogs using classical techniques. These analogs provided us with valuable insight as to the importance of chirality, lipid solubility, spatial orientation, and important functional groups of the pharmacophore and allow for the optimization of the antiproliferative actions of this set of drugs.

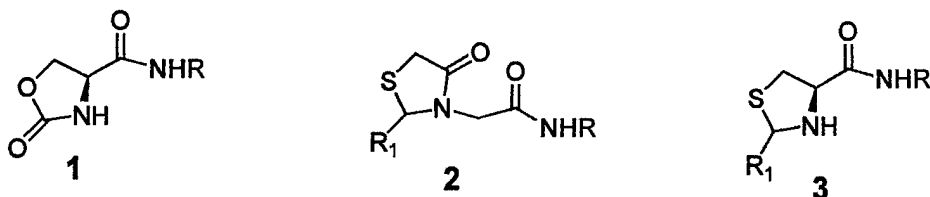
More recently we have discovered a new set of 2-arylthiazolidine-4-carboxylic acid amides that show sub micromolar anticancer activity in the cell lines described above. We have found new synthetic schemes for these new compounds and have expanded our structure activity relationships into the substitutions for activity against PC-3, DU-145, LNCaP, PPC-1 and TSU-Pr1 prostate cell lines using the RH7777 cell line as a control cell line for comparison. We are now optimizing these agents for potential use in prostate cancer.

Due to time and budgetary constraints, only a limited set of compounds including will be carried forward to these studies in the next year of the grant. These experiments are designed to provide an initial pharmacologic assessment of our most promising compounds, focusing specifically on (1) their in vivo toxicity and (2) their in vivo antitumor efficacy in prostate tumor xenografts. Animal care guidelines at our institution will be strictly followed for these studies. We have requested a year no cost extension to carry out these study and optimizing 2-arylthiazolidine-4-carboxylic acid amides (ATCAAs) for prostate cancer.

Task 1. Synthesis of serine amide phosphate (SAP) and serine diamide phosphate (SDAP) analogs

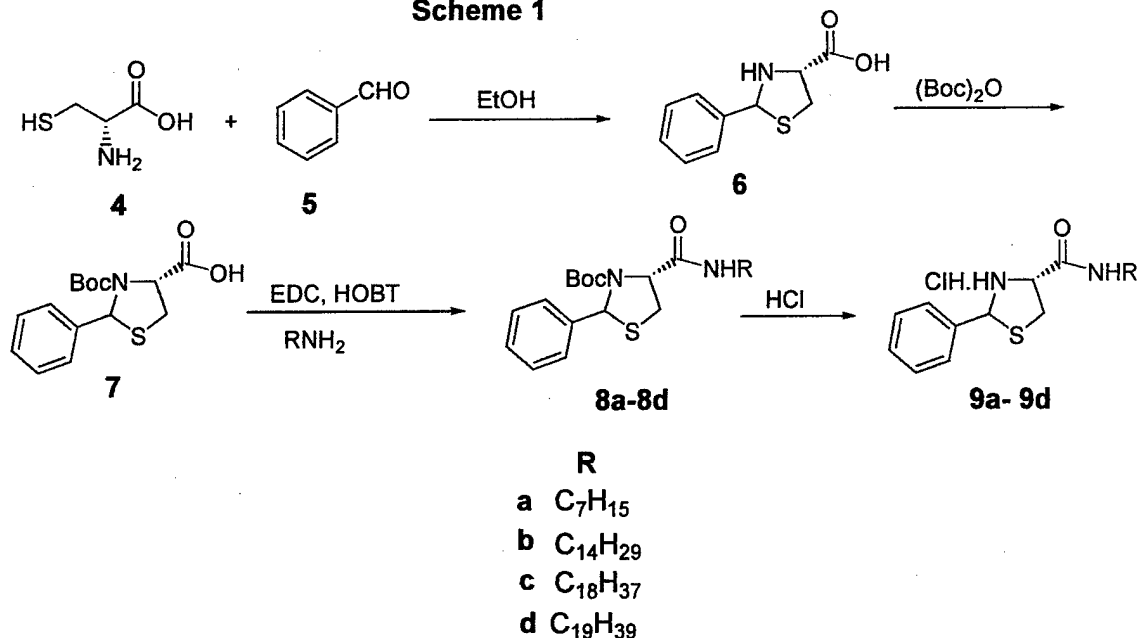
Year 3: We will take the advantage of biological studies in year 1 and 2 to design new generation of analogs of SAP and SDAP in order to optimize the inhibition of proliferation of prostate cancer cells.

This task was successfully completed. In year 2 we proposed the design and synthesis of a new series of conformationally restricted analogs represented by compounds **1**, **2** and **3** as shown below. The heterocyclic scaffold (oxazolidine, thiazolidinone or thiazolidine) serves as a nonhydrolyzable metabolically stable phosphate mimic. To test this hypothesis we have synthesized a series of above-mentioned analogs and evaluated for their ability to inhibit the growth of five human prostate cancer cell lines. Oxazolidine analog **1** was less cytotoxic in all five prostate cancer cell lines. Compared to oxazolidine derivative, thiazolidinones were more potent but were less cytotoxic than SAPs. Interestingly, thiazolidinones (**2**) demonstrated improved selectivity against non-tumor RH7777 cells. The most potent and selective compounds were obtained with the thiazolidine scaffold. With these very encouraging preliminary results, to further optimize the thiazolidine pharmacophore in terms of cytotoxicity and selectivity, we proposed the design, synthesis and biological evaluation of several new thiazolidine analogs in year 3 and the details are described in this report. ¹HNMR, ¹³CNMR, IR and mass spectrometry confirmed the structures of all new compounds synthesized.



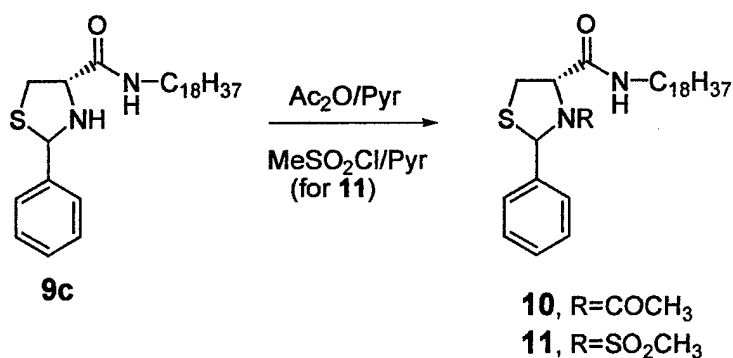
Examination of the cytotoxic effects of **9a-9c** (Scheme 1) showed that as the chain length increased from C₇ to C₁₈, the potency also increased. However, a further increase in the alkyl chain length by one carbon unit (**9d**) caused a significant loss of activity. Interestingly, the C₁₄ derivative (**9b**) demonstrated higher potency than **9a**, but was 8-fold less selective against the RH7777 cell line. Thus, an alkyl chain with C₁₈ unit was optimal for maintaining the potency and selectivity observed in this series of compounds.

Scheme 1



To understand the effect of derivatization of the secondary amine functionality compounds **10** and **11** were synthesized as shown in Scheme 2.

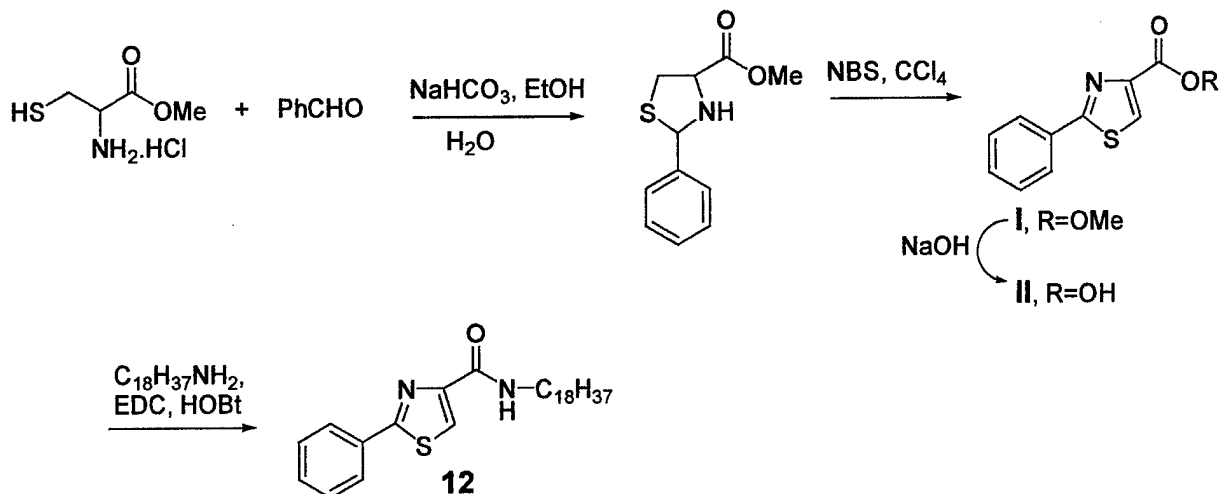
Scheme 2



To understand the effect of unsaturation on potency and selectivity, and to overcome the problems associated with stereoisomers, we replaced the central thiazolidine core in **9c** with a thiazole ring (Scheme 3). However, thiazole derivative (**12**) did not show any

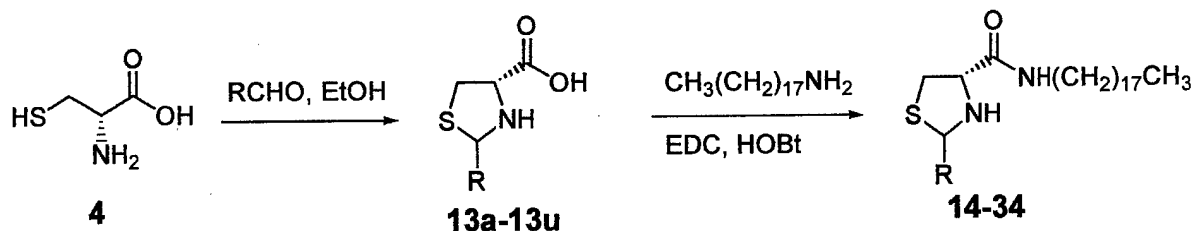
activity below 20 μ M in both prostate and RH7777 cells, which suggests that thiazolidine ring with two chiral centers plays an important role in providing potency and selectivity.

Scheme 3



Replacements of the phenyl ring in **9c** with a heterocycle, such as an indole, pyridine or furan ring was investigated by synthesizing analogs **17-19**. Introduction of a methylene spacer separating the phenyl ring and the thiazolidine ring furnished a compound **16** as shown below. Replacement of the phenyl ring in **9c** with an alkyl or cyclohexyl group afforded compounds **14** and **15**. The synthesis and cytotoxicity data of compounds **20-34** provides a summary of a broad survey of phenyl ring substituted analogs. All these compounds were synthesized as shown in Scheme 4.

Scheme 4



Compd	R
13a	n-dodecyl
13b	cyclohexyl
13c	benzyl
13d	3-indolyl
13e	3-pyridinyl
13f	3-furanyl
13g	4-dimethyl amino phenyl
13h	3-hydroxyphenyl
13i	4-methoxyphenyl
13j	3,4-dimethoxyphenyl
13k	3,4,5-trimethoxyphenyl
13l	4-acetylamino phenyl
13m	4-fluorophenyl
13n	4-bromophenyl
13o	4-nitrophenyl
13p	4-cyanophenyl
13q	3,5-difluorophenyl
13r	2,6-dichlorophenyl
13s	3-bromo-4-fluorophenyl
13t	4-methylphenyl
13u	biphenyl

P.I. Duane D. Miller Ph.D.
The University of Tennessee

Task 2. Determine activity of SAP and SDAP analogs in Prostate cell lines

Year 3: We will determine the activity of the synthesized analogs in Specific Aims 1.2.3.4.5.6 in PC-3, DU-145 and LNCaP cell lines.

This task was completed successfully. We have tested the cytotoxicity of the synthesized compounds in PC-3, DU-145 and LNCaP prostate cancer cell lines as proposed earlier. In addition to these cell lines we have also tested in two additional PPC-1 and TSU-Pr1 prostate cancer cell lines. To determine the selectivity of these compounds we have also tested them in non-prostate cancer cells RH7777 cells (data shown in Table1)

Task 3. Determine the activity of SAP and SDAP analogs in prostate tumor xenograft in mice

Year 3: We will select the most promising agents from specific Aim. 6 of the PC-3, DU-145 and LNCaP cell lines studied in year 1, 2 and 3 for In Vitro Efficacy against Prostate Tumor Xenografts in mice (Specific Aim C. 7)

Starting with SAPs, we identified a series of novel and cytotoxic thiazolidine amides based on a 4-thiazolidine carboxylic acid scaffold. Among this series, we synthesized and carried out a detailed SAR studies and evaluated their antiproliferative activity against five human prostate cancer cell lines and RH7777 cells (negative controls). This data (Table 1) suggests that introduction of ring activating groups on the phenyl ring resulted in increasing potencies for prostate cancer cell lines leading to discovery of several new anticancer agents with low/sub micromolar cytotoxicity and high selectivity. Based on the results of this cytotoxicity study we chose four compounds (**9b**, **9c**, **24** and **25**) for the xenograft studies in mice. We have completed the synthesis of gram quantities of these four analogs and in vivo studies are in progress in our laboratory.

Key Research Accomplishments

- Identified 2-Aryl-thiazolidine-4-carboxylic acid amides (ATCAAs) as a new class of cytotoxic agents for prostate cancer.
- Carried out systematic and detailed SAR of ATCAAs by synthesizing a large number of derivatives and evaluated them for their inhibitory activity towards the growth of five human prostate cancer cell lines.
- Observed that derivatization of amine functionality in ATCAAs to the corresponding amides or sulfonamides results in loss of biological activity.
- Observed that replacement of the 2-phenyl ring in ATCAAs by an alkyl or cyclohexyl groups and introduction of a methylene spacer separating the phenyl ring and the thiazolidine ring reduced the potency.
- Investigated the effect of various substitutions on the 2-phenyl ring on cytotoxicity and selectivity. Introduction of electron-donating groups on the phenyl ring resulted in increasing potencies with enhanced selectivity, leading to discovery of several new anticancer agents with low/sub micromolar cytotoxicity.

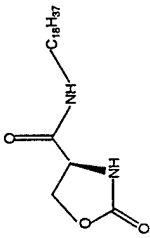
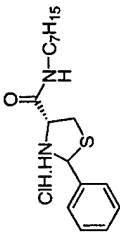
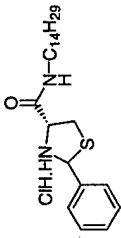
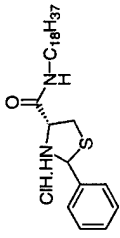
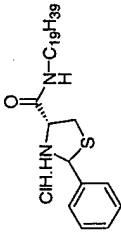
Reportable Outcomes (copies attached)

- Discovery of 2-Arylthiazolidine-4-carboxylic acid amides as a New Class of Cytotoxic Agents for Prostate Cancer
Veeresa Gududuru, Eunju Hurh, James Dalton, and Duane Miller. 227th ACS National Meeting, Anaheim, CA, March 28-April 1, 2004.
- 2-Phenylthiazolidine Derivatives of Lysophosphatidic Acid as a New Class of Anticancer Agents
Eunju Hurh, Veeresa Gududuru, Duane Miller and James Dalton. 95th Annual AACR Meeting, Orlando, FL, March 27-31, 2004.
- Synthesis and Antiproliferative Activity of 2-Aryl-4-oxo-thiazolidin-3-yl-amides for Prostate Cancer
Veeresa Gududuru, Eunju Hurh, James Dalton and Duane Miller. 31st Annual MALTO Meeting, Memphis, TN, May 16-18, 2004.
- Synthesis and biological evaluation of novel cytotoxic phospholipids for prostate cancer
Veeresa Gududuru, Eunju Hurh, Gangadhar Durgam, Seoung Soo Hong, Vineet Sardar, Huiping Xu, James T. Dalton, Duane D. Miller, *Bioorg. Med. Chem. Lett.* 2004, 14, 4919-4923.
- Synthesis and antiproliferative activity of 2-Aryl-4-oxo-thiazolidin-3-yl amides for prostate cancer
Veeresa Gududuru, Eunju Hurh, James Dalton, and Duane Miller, *Bioorg. Med. Chem. Lett.* 2004, 14, 5289-5293.
- Efficient Microwave Enhanced Synthesis of 4-Thiazolidinones
Veeresa Gududuru, Viet Nguyen, James T. Dalton and Duane D. Miller, *Synlett.* 2004, (in press).
- Discovery of 2-Arylthiazolidine-4-carboxylic acid amides as a New Class of Cytotoxic Agents for Prostate Cancer
Veeresa Gududuru, Eunju Hurh, James Dalton, and Duane Miller, *J. Med. Chem.* 2004 (submitted).

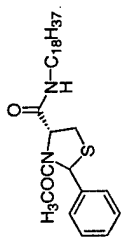
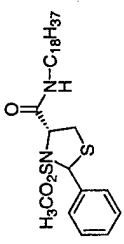
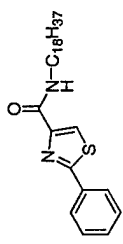
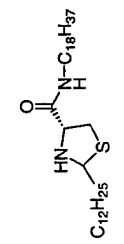
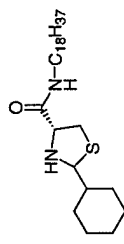
Conclusions

We have discovered a new set of 2-arylthiazolidine-4-carboxylic acid amides (ATCAAs). This report shares the critical structure activity relationships (SAR) for optimum activity in prostate cancer cells. We have shown sub micromolar anticancer activity in the PC-3, DU-145, LnCaP, PPC-1 and TSU-Pr1 prostate cell lines using the RH7777 cell line as a control cell line for comparison (see Table 1). We have found new synthetic schemes for these new compounds and have expanded our structure activity relationships into the substitutions patterns for optimum anti-prostate cancer activity. We are now investigating the action of several of these newly found anti-prostate cancer agents *in vivo*.

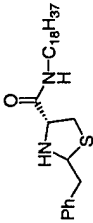
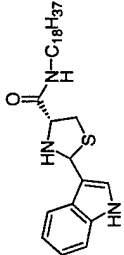
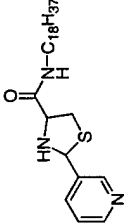
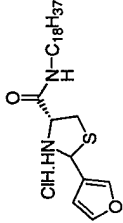
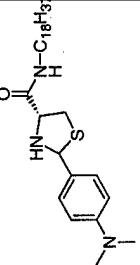
Table 1

Compound ID	Structure	IC ₅₀ (μM)					
		RH7777	DU145	PC-3	LNCaP	PPC-1	TSU-Pr1
1		35.2	22.1	17.2	31.3	11.6	27.7
9a		52.2	44.9	38.5	12.4	34.7	28.0
9b		3.4	2.4	3.0	1.4	1.3	2.0
9c		25.6	5.4	7.8	2.1	2.0	5.0
9d		No activity	> 20	No activity	13.6	16.8	> 20

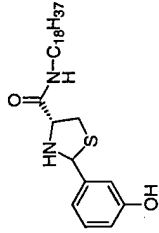
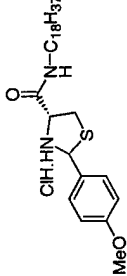
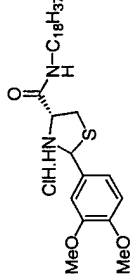
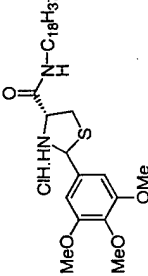
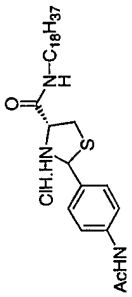
P.I. Duane D. Miller Ph.D.
The University of Tennessee

Compound ID	Structure	IC ₅₀ (μM)					
		RH7777	DU145	PC-3	LNCaP	PPC-1	TSU-Pr1
10		>20	~20	~20	16.1	12.6	>20
11		>20	>20	>20	>20	>20	>20
12		>20	>20	>20	>20	>20	>20
14		~20	8.9	15.0	11.9	13.0	10.7
15		>20	>20	>20	12.8	9.3	>20

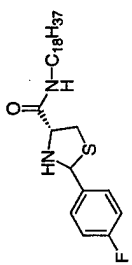
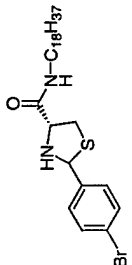
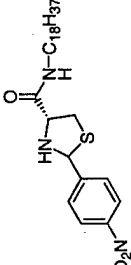
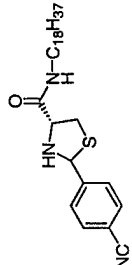
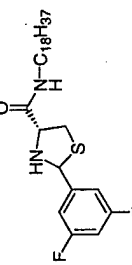
P.I. Duane D. Miller Ph.D.
The University of Tennessee

Compound ID	Structure	IC ₅₀ (μM)					
		RH7777	DU145	PC-3	LNCaP	PPC-1	TSU-Pr1
16		> 20	15.3	16.4	4.4	4.0	11.2
17		> 20	8.9	11.5	2.1	1.3	4.4
18		10.5	7.5	9.2	3.6	2.9	7.8
19		10.4	6.6	8.1	1.7	1.1	4.2
20		> 20	5.3	6.0	1.6	1.1	3.0

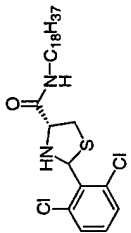
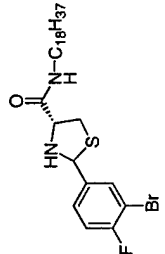
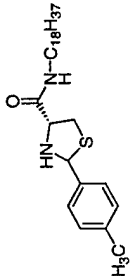
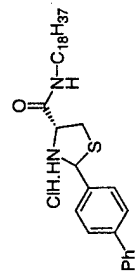
P.I. Duane D. Miller Ph.D.
The University of Tennessee

Compound ID	Structure	IC ₅₀ (μM)					
		RH7777	DU145	PC-3	LNCaP	PPC-1	TSU-Pr1
21		31.0	5.7	6.7	1.7	1.2	4.0
22		>20	8.7	~20	2.1	1.5	ND
23		10.3	4.5	5.2	0.85	0.58	2.4
24		11.4	3.9	4.0	0.82	0.48	2.4
25		21.1	3.1	5.6	1.3	0.55	0.94

P.I. Duane D. Miller Ph.D.
The University of Tennessee

Compound ID	Structure	IC ₅₀ (μM)					
		RH7777	DUI45	PC-3	LNCaP	PPC-1	TSU-Pr1
26		17.4	5.7	6.8	1.9	2.1	5.4
27		> 20	13.8	17.3	5.1	3.7	18.3
28		~ 20	15.3	~ 20	8.4	15.3	15.9
29		>20	>20	>20	5.9	5.0	>20
30		>20	>20	>20	11.2	10.6	>20

P.I. Duane D. Miller Ph.D.
The University of Tennessee

Compound ID	Structure	IC ₅₀ (μM)					
		RH7777	DU145	PC-3	LNCaP	PPC-1	TSU-Pr1
31		> 20	> 20	> 20	13.1	17.1	~ 20
32		~ 20	11.3	13.5	3.0	4.7	14.0
33		> 20	10.5	12.8	1.9	1.9	8.0
34		> 20	> 20	> 20	> 20	> 20	> 20



Veeresa Gududuru¹, Eunju Hurh², James T. Dalton³, and Duane D. Miller¹

¹Department of Pharmaceutical Sciences, College of Pharmacy, University of Tennessee, Memphis, TN 38163

Department of Pharmaceutical Sciences, College of Pharmacy, University of Tennessee, Memphis, TN 38163
Division of Pharmaceutics and Pharmaceutical Chemistry, College of Pharmacy, The Ohio State University, Columbus, OH 43210

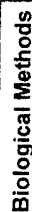
Prostate cancer is the single most common cancer in American males and is the second leading cause of prostate deaths in men in the United States. None of the conventional approaches to cancer therapy have proved successful for prostate cancer. It is also known that certain treatments—radiation therapy, radical prostatectomy or hormonal therapies—can have detrimental effects on urinary, bowel, and sexual functions. Thus, development of chemopreventive agents without any side effects would be an attractive proposal for the treatment of prostate cancer.

Prostate cancer arises from a small series of cytotoxic serine amines called sphingosines (SAPs) for prostatic acid sphingomyelinase. In a more recent study, we found that the IC₅₀ values ranging from about 2 µM to 50 µM are very effective against these cytotoxic serine amines in cultured primary prostate cancer cells and healthy cells. It is also evident that phosphatidic group in this class of compounds is responsible for cytotoxicity and lipidyl cations. To improve the selectivity, cytotoxicity and metabolic stability, we made some cyclophosphamide related structural changes on SAPs, which led us to discovery of a new class of 2-arylazobenzothiazole cyclophosphamide amide mixtures with IC₅₀ values at low micromolar range and enhanced selectivity. This new series of compounds showed promising results in inhibiting growth of DU145, LNCaP, PC-17, and TSU-Prt human prostate cancer cell lines for their cytotoxicity. The details of synthesis, structure-activity relationship (SAR), and resulting preclinical studies will be presented in this presentation.

G-protein coupled receptors are a family of membrane-bound proteins that are involved in the proliferation and survival of prostate cancer cells, induced by binding of lysophospholipids (LPL). ¹ The importance of G protein-dependent pathways in the regulation of cell growth and survival has been demonstrated by the observation that the growth of androgen-independent prostate cancer cells is inhibited by treatment with pentakis (5-phenyl-1,3,4-oxadiazol-2-yl) phosphoramide (SPH) and sphingosine (SPH), which are known to be lipid mediators generated via the regulated breakdown of membrane phospholipids that is known as the PI3K and Ras signaling pathway. Prostate cancer represents a unique disease in which to exploit the activity of these LPL, kinase and Ras antagonists. Advanced prostate cancer expresses LPL receptors ² and, these pathways are widely viewed as one of the most promising new approaches to cancer therapy ³. Thus, these pathways are widely used as a target for the treatment of advanced, androgen-refractory prostate cancer. Despite the promise of this approach, there are no clinically available therapies that selectively exploit or inhibit LPL or PI3K signaling. Our interest in development of LPL agonists and antagonists. As part of this study, we recently identified a novel class of LPL agonists and phosphatases (SAP-*t*) that are effective in killing specific prostate cancer cell lines and human and mouse compounds showed low micromolar cytotoxicity, they were non-competitive and did not inhibit LPL activity in cell free systems (data not shown). We hypothesized that domestic compounds that are metabolically unstable, but which can penetrate prostate group in our prostate cancer cell lines, would be effective in killing prostate cancer cells. To this end, we modified our initial approach and designed a new series of 2-arylphosphazido-4-carboxylic acids (ATCAAs) in which the 2-arylphosphazido moiety was introduced as a phosphate mimic (Figure 1).



Commercially available cysteine (R or S form) was allowed to react with various aldehydes in EtOH to give acid 3, which was converted to corresponding N-Boc derivative (4). Reaction of N-Boc-2-aminoethylolacetic acid-carboxylic acid (4) with various allyl amines under standard coupling conditions using EDC and HOBT gave corresponding amides 5. Treatment of these amides with HCl gave the target compounds in high yield (Scheme 1). N-Sulfonyl and N-acyl derivatives (13, 8) were synthesized from 14 as shown in Scheme 2. For the preparation of unsaturated thiazole derivative, cysteine was converted to thiazole carboxylic acid (10), which was coupled with octadecyl amine to give 21 as shown in Scheme 3.



We examined the cytotoxicity of thiazolidinone derivatives on five human prostate cancer cell lines (DU-145, PC-3, LNCaP, TSU-1, and a negative control cell line (RW777)) using the sulfinamide B (SRB) assay. Cells were exposed to a wide range of concentrations (0 to 100 μ M) of the positive control, doxorubicin, and the thiazolidinone derivatives for 96 h in 96-well plates. Cells were fixed with 10% trichloroacetic acid, washed five times with water. The plates were stained overnight and fixed cells were then stained with SRB solution. The cellular protein-bound SRB was then eluted with 5% trichloroacetic acid. The absorbance of the eluate was obtained by nonlinear regression analysis using WinNonlin. For comparative purposes and to understand the sequence of events that lead to cell death, we treated DU-145 and LNCaP-3 cells with 100 μ M of doxorubicin or 100 μ M of thiazolidinone derivatives for 96 h. The results are summarized in Table 1.

Thiazolidine analogs are very effective in killing prostate cancer cell lines with IC_{50} values ranging from about 1 μ M to 100 μ M. Compounds 14 and 15 were the most potent, with IC_{50} values of 1.47 and 1.57 μ M, respectively. Shorter alkyl chain lengths (i.e., 12, 13, 17) showed a difference in their cytotoxicity in an of the order of 10-fold. The presence of a thiazolidine ring with a molecular "target" that is not present in the substrate or less critical in RHHHT7 cells (16, 18) was less potent than the parent thiazolidine compared to the 2-aryl thiazolidine analogs (19, 20). The presence of a thiazolidine ring with a 2-phenyl group (21) was less potent than the parent thiazolidine compared to the 2-aryl group of 14 with an alkyl or heteroaryl group resulted in loss of biological activity. We observed that several of the thiazolidine analogs were as potent inhibitors of tumor cell proliferation as 5-FU. We necessarily better in many cell lines. Compared to SAPs, ATACAs in which the 2-arylthiazolidine moiety was introduced as a phosphate mimic showed selective anti-prostate cancer activity in all of the tumor and negative control cell lines. These results suggest that the thiazolidine moiety is a promising lead for the development of novel agents that focus on optimization of the alkyl chain length. Investigation of the importance of chirality and independent studies of their structural requirements of the thiazolidine analogs for enhanced selective cytotoxicity in prostate cancer cell lines.

This work is supported by a grant from the Department of Defense (DAMD17-01-1-0830).

Table 1. Structures and Antiproliferative Activities of ATCAAs In Prostate Cancer Cell Lines (IC₅₀ in μ M)

Sl. No.	Structure	40°C	50°C	60°C	70°C	80°C	90°C	100°C
1		ND	108	20	26	34	16	11
2		2.5	3.2	2.4	3.3	1.6	1.1	
3		ND	108	100	>100	100	>100	
4		52.2	44.9	38.5	12.4	34.1	28.0	
5		3.4	2.4	3.0	1.4	1.3	2.0	
6		25.6	1.4	7.8	2.1	2.0	1.0	
7		>20	>20	>20	>20	>20	>20	
8		>20	>20	>20	12.6	>20	>20	
9		19.1	1	>10	6.3	4.0	>10	
10		>20	8.1	>20	2.1	1.5	ND	
11		>20	>20	>20	11.2	10.6	ND	
12		>20	>20	>20	5.9	5.0	ND	
13		>20	>20	>20	>20	>20	ND	
14		>20	>20	>20	>20	>20	>20	
15		>20	8.9	15.0	11.9	13.0	10.7	
16		10.5	7.5	9.2	3.6	2.9	7.8	

References

1. Kuo, B.F. and Y. Datta, Essential role for G proteins in prostate cancer growth and signaling. *J Urol*, 2000, 164(6): 2116-2122.
2. Guo, C., L.M. Lital, and D.T. Price, Mitogenic signaling in androgen sensitive and insensitive prostate cancer cell lines. *J Urol*, 2000, 163(3): p. 1027-32.
3. DeBartorelli, L. and Y. Datta, Biochemical interrelationships of androgen independent prostate cancer cells. *J Urol*, 2000, 163(3): p. 1033-39.
4. Sax, A., L. Lommen, G. Romero, K. Qiao, T. Hatz, K. Ribben, H. Inuyama, et al., Inhibition of androgen receptor and metastases after orthotopic implantation of the human prostate cancer cell line PC3 in nude mice. *Prostate Cancer*, 1999, 2(1): p. 36-40.
5. Fabbas, Y., G. Romero, K. Qiao, T. Hatz, K. Ribben, K. Inuyama, et al., G protein-coupled receptors in prostate cancer. *J Urol*, 2000, 163(3): p. 1039-43.
6. Murto, H., H. Huang, H. Schmidt, L.J. Smith, O.T. Tindall, et al., Role of tyrosine signaling in survival and progression of LNCaP prostate cancer cells to the androgen-refractory state. *Endocrinology*, 2001, 141(11): p. 4795-805.
7. Kuo, B.F. and C.L. Sawyers, The phosphoinositide 3-kinase/Akt pathway in human cancer. *Nat Rev Cancer*, 2002, 2(8): p. 850-61.
8. Miller, D.D., J. Gabor, David, J. Wang, T. Sander, Virese, M. Elrod, Don B. Xu, Weiping, Biele, David, L. Wang, Dant, Lian, Nancy Fisher, David, J. Wang, T. Sander, Virese, Naser, N. El, p. 633-2003.



2-Phenylthiazolidine Derivatives of Lysophosphatidic Acid as a New Class of Anticancer Agents

Junju Huh¹, Veerendra Gududuru², Duane D. Miller², and James T. Dalton¹

¹Division of Pharmaceutics and Pharmaceutical Chemistry, College of Pharmacy, The Ohio State University, Columbus, OH 43210
²Department of Pharmaceutical Sciences, College of Pharmacy, University of Tennessee, Memphis, TN 38163

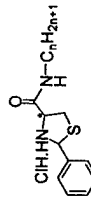


Abstract

Lysophosphatidic acid (LPA) is a growth factor that promotes cell proliferation, cell survival, tumor cell invasion, and metastasis via activation of G-protein coupled receptors. A series of LPA analogs with a 2-phenylthiazolidine ring, a bioisosteric replacement of the phosphate moiety, were synthesized as individual stereoisomers and tested for their growth inhibitory activity in prostate cancer cell lines. Cytotoxicity of the compounds was determined by the sulforhodamine B assay in 96-well plates in PC-3, LNCaP, DU 145, PPC-1, and TSU-Pr1 human prostate cancer cells exposed to increasing concentrations of the compounds for 96 hours. IC_{50} values obtained by nonlinear regression analysis ranged from 1 μ M to about 50 μ M. The length of the alkyl chain attached to the phenylthiazolidine ring via an amide bond had a significant influence on cytotoxicity. Compounds with a 14-carbon chain (C14) were the most potent, followed by C18 and C7. LPA-nonspecific RH7777 rat hepatoma cells were employed as a control cell line to discriminate LPA receptor-mediated effects from nonspecific cytotoxicity of the analogs. A compound with a C18 chain demonstrated selective activity against prostate cancer cells (IC_{50} of 2 μ M to 8 μ M) when compared to RH7777 cells (IC_{50} of 26 μ M). In addition, the (R) isomer of this compound showed approximately 2-fold higher activity than the (S) isomer against prostate cancer cells. Further, no stereoselective effect was observed in RH7777 cells. The (R) isomer at 3 μ M induced apoptosis in LNCaP cells. We also examined the effect of these compounds on AKT phosphorylation status using immunoblot analysis. Treatment of LNCaP cells with a representative compound at 10 μ M resulted in complete loss of phospho-AKT within 6 hours. Additional studies to identify and verify molecular target(s) of these compounds are ongoing in our laboratory.

Keywords: cytotoxicity; prostate cancer; apoptosis

Results



Cell Line	Compound	n	1	2	3	4
DU 145	Isomer	(R)	44.9	2.4	5.4	7.1
PC-3			38.5	3.0	7.8	>10
LNCaP			12.4	1.4	2.1	6.3
PPC-1			34.7	1.3	2.0	4.0
TSU-Pr1			28.0	2.0	5.0	~10
RH7777			52.2	3.4	25.6	19.1

Introduction

Various therapies for advanced prostate cancer, including chemotherapy, have not proven satisfactory. One promising drug development strategy for prostate cancer involves identifying and testing agents that interfere with growth factors and other molecules participating in signaling pathways. LPA and sphingosine 1-phosphate are phospholipid growth factors that elicit their effects (i.e., stimulation of cell proliferation and tumor cell invasion) via multiple subtypes of membrane spanning G-protein coupled receptors (GPCRs), collectively referred to as lysophospholipid receptors. Among downstream mediators of these GPCRs, phosphoinositide 3-kinase (PI3K) and AKT (also known as protein kinase B) are two major effectors of cell survival and cell proliferation. Therefore, inhibition of lysophospholipid receptors to antagonize/inhibit molecules in this signaling pathway will result in reduced cell proliferation and survival. Our laboratory recently identified and tested a novel series of serine amide phosphate derivatives for their growth inhibitory activity in prostate cancer cells. To improve metabolic stability, pharmacokinetic properties, and cellular penetration, a thiazolidine moiety was introduced in place of the phosphate group of these serine amide phosphates. As further efforts to examine structure-activity relationships and to identify molecular target(s) of these new series of thiazolidine analogs, the present studies examined their growth inhibitory activities, apoptotic effects, and effect on AKT phosphorylation status in prostate cancer cell lines (DU 145, PC-3, LNCaP, PPC-1, and TSU-Pr1).



LNCaP cells



Lane 1: 100 bp DNA marker
Lane 2: 5 μ M of Compound 2 for 36 h
Lane 3: 3 μ M of Compound 2 for 24 h
Lane 4: 5 μ M of Compound 2 for 24 h
Lane 5: 3 μ M of Compound 2 for 48 h
Lane 6: 3 μ M of Compound 2 for 72 h
Lane 7: 8 μ M of Compound 2 for 96 h
Lane 8: 8 μ M of Compound 2 for 108 h

Enhancement Factor = $\frac{OD_{490nm} \text{ in Treated Cells}}{OD_{490nm} \text{ in Control Cells}}$

Cell Line	Compound 2	Compound 3	Compound 4
	2 μ M	5 μ M	10 μ M
PC-3	1.8	18.7	54.0
LNCaP	14.1	75.4	80.7
RH7777	2.6	3.2	2.5
	Not determined	Not determined	Not determined

Methods

Cell Culture and Cytotoxicity Assay (Sulforhodamine B assay)

Cancer cell lines were obtained from American Type Culture Collection (Manassas, VA). Prostate cancer cells and RH7777 cells were maintained in RPMI 1640 and DMEM medium supplemented with 10% fetal bovine serum and maintained in 5% CO₂/95% air humidified atmosphere at 37 °C. Cells were plated in 96-well plates at a density of 10,000 cells per well in growth medium containing a wide range of analogs at 37 °C. Cells were allowed to attach overnight, and the cells were then treated with 10% trichloroacetic acid at 4 °C for several hours before washing 5 times with water. The plates were air dried overnight. After staining, SRB solution was decanted, and plates were quickly rinsed 5 times with water. The cellular protein-bound SRB was then dissolved in 10 mM Tris base (pH 10.5) for 40 min. The absorbance at 540 nm was measured using a plate reader. Percentage of cell survival was calculated by absorbance at 540 nm. The concentration of drug that inhibited cell growth by 50% (IC_{50}) was determined by nonlinear regression using WinNonlin (Pharsight Corporation, Mountain View, CA).

DNA Fragmentation Assay

Apoptosis was assayed by agarose gel electrophoresis. LNCaP cells were treated with a thiazolidine derivative for 24 to 108 hours. Total DNA was extracted from 2 $\times$ 10⁶ cells by lysis with lysis buffer, followed by phenol extraction. DNA was precipitated in ethanol, DNA was reconstituted in Tris-EDTA buffer, separated on agarose gels, and stained with ethidium bromide. Quantification of DNA fragmentation by Cell Death ELISA (Roche, Mannheim, Germany) utilizing monoclonal antibodies specific for DNA and histones was used to quantify degree of DNA fragmentation. The assay measures DNA-histone complexes (mono- and oligonucleosomes) released into cytoplasm during apoptosis. RH7777 cells were employed because of nonspecific cytotoxicity of compound 2 in receptor-negative RH7777 cells as well as receptor-positive prostate cancer cells.

AKT Inhibition

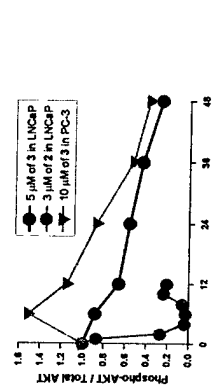
30 μ g of total cellular protein from untreated control cells and compound-treated cells were separated by SDS-PAGE, transferred to nitrocellulose membrane, and total AKT and phospho-AKT were probed with anti-AKT and anti-phospho-AKT antibody specific for AKT phosphorylated at Ser473, respectively (Cell Signaling Technology, Beverly, MA). The immunoblots were visualized by enhanced chemiluminescence, and changes of relative levels of phospho-AKT compared to total AKT by analog treatment were quantified by densitometric analysis.

Conclusions

- Compound 1 with a C₁₄ alkyl chain was generally inactive showing IC_{50} > 10 μ M in all the cell lines tested.
- Compound 2 with a C₁₄ alkyl chain was the most potent inducer of apoptosis and inhibitor of tumor cell growth. Apoptotic activity of this compound was selective in prostate cancer cells despite nonspecific cytotoxicity in RH7777 negative control cells. Compound 2 at 3 μ M completely inhibited AKT phosphorylation after 4 hour treatment, correlating with high cytotoxicity.
- Compound 3 with a C₁₄ alkyl chain demonstrated selective cytotoxicity against prostate cancer cells (IC_{50} of 2 μ M to 8 μ M) without any growth inhibitory effect up to 10 μ M in receptor-deficient RH7777 cells. It also induced apoptosis in a dose-dependent manner, and inhibited AKT phosphorylation without affecting AKT protein expression levels.
- Compound 4 was less potent in inhibiting prostate cancer cell growth than the R isomer (compound 3), suggesting the importance of stereochemistry for antiproliferative effects. Stereoselective cytotoxicity was also observed in apoptotic activity with compound 3 being more potent inducer of apoptosis at all the concentrations tested.
- Thiazolidine analogs of lysophospholipids represent a novel class of potential anticancer agents in prostate cancer. Further studies will focus on correlating the cytotoxic effects of the analogs with their roles in lysophospholipid receptor signaling, identifying molecular target(s) of the analogs, and understanding structural requirements of the analogs for selective cytotoxicity.

Acknowledgement

This work is supported by a grant from the USAMRMC (#PC010431).



Abstract

new therapies for advanced prostate cancer, including chemotherapy, have not been satisfactory. One promising drug development strategy is to identify and evaluate identifying and testing agents that interfere with growth factor receptors and downstream signaling pathways. LPA (lysophosphatidic acid) and lysophosphatidyl-L-serine are phospholipid growth factors that elicit their effects (i.e., stimulation of cell proliferation and tumor cell invasion) via multiple subsets of membrane spanning G-protein coupled receptors (GPCRs), collectively referred to as lysophosphatidic acid receptors. Among downstream mediators of these GPCRs, the mitogen-activated protein kinase (MAPK) pathway is one of the major stimulators of cell proliferation and cell invasion. The MAPK pathway is also a major stimulator of cell proliferation and cell invasion in prostate cancer. In this presentation, we have identified and tested a novel class of serine amide phosphates (SAPs). Our laboratory recently identified and tested a novel class of serine amide phosphates (SAPs) for their growth inhibitory activity in prostate cancer cells. To improve metabolic stability, pharmacokinetic properties, and cellular penetration, a triazole nucleoside moiety was introduced in place of the phosphate group of the SAPs. This led us to discovery of a new class of 2'-deoxy-2'-methyl-3-yl triazole nucleoside SAPs. Twelve sets of compounds were evaluated in PC-3, DU-145, LNCaP, and TSU-PR1 cell lines. The results of these studies will be presented. The details of synthesis, structure-activity, and cell lines for their cytotoxicity. The details of the results of these studies will be presented in this presentation.

Introduction

thine amide phosphates^{1,2} (SAPs) were identified as a new series of compounds that actively kill specific prostate cancer cell lines and represent a novel class of anticancer agents for the treatment of prostate cancer (Figure 1). We made modifications to SAPs in the phosphate head group region and this group was replaced a thiazolidone moiety toward improving pharmacokinetic properties and cellular activity in human prostate cancer cell lines.

dro² et al. have postulated that 4-thiazolidinones may be recognized as diphosphate mimics, and using this scaffold they synthesized and evaluated some 4-thiazolidinones designed to inhibit the bacterial enzyme MurB. Based on this hypothesis, we prepared a new series of thiazolidinone derivatives as shown in Figure 2. In the present work, we report the synthesis, structure-activity relationship (SAR) studies and the antiproliferative activity of type I compounds (Figure 2), in five human prostate cancer cell lines.

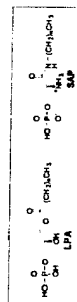


Figure 1

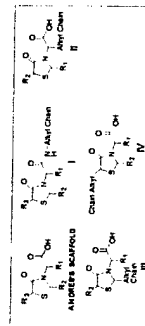
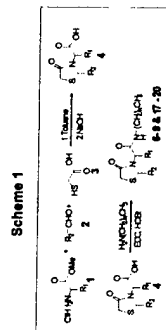
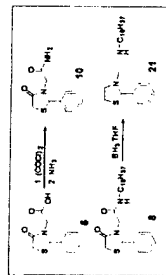


Figure 2

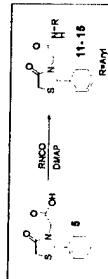
Chemistry



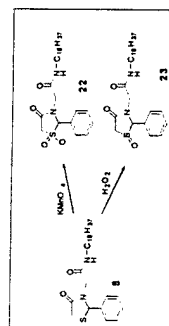
Scheme 1



Scheme 2



Scheme 3



Scheme 4

Biological Methods

We examined the cytotoxicity of thalidomide derivatives in five human prostate cancer cell lines (DU-45, PC-3, UICP, PC-9, and LNCaP) and a negative control cell line (RW7777) that lacks LPI⁺ receptor using the anti-proliferative agent, 1- α ,25-dihydroxyvitamin D₃ (1,25(OH)₂D₃) [1,25(OH)₂D₃], and the anti-angiogenic agent, thalidomide (T) and thalidomide derivatives (0 to 100 μ M) of the particular compound for 96 h in 96 well plates. Cells were treated with 10% thiorocetic acid, washed five times with PBS, and then the cells were stained with crystal violet in a 96 well plate solution. The cellular protein-bound SSB was measured using a plate reader. Cell numbers at the end of the treatment were measured. IC₅₀ values were obtained by nonlinear regression analysis using WinNonlin[®]. For comparative purposes, and to understand the degree of cytotoxicity we tested thalidomide and thalidomide derivatives in the LNCaP cell line. The results are summarized in Table 1, 2, 3.

Table 1 (IC₅₀ in μ M)[illegible]

Acknowledgements

This work is supported by a grant from the Department of Defense (DAMD17-01-1-0830).

Summary

References

- Miller, D. D., T. Gibson, James T. Sander, Virend M. Eshod, Don B. Xu, Huiqing Baker, David L. Wang, David L. Lums, Larry P. Fletcher, David J. Wang, Tamara Nuss, J. U.S. Patent, Ser. No. 87/133,603.
22. Gangstcher, Vladimir, Seung Soo Hong, Emily Hung, Huiqing Xu, Jim Dehon, and David M. Packer. 1992. *Abstracts of the 22nd Annual Meeting, New Orleans, LA*. Boston: S. V. Dushkova.
23. Andre, C., and B. B. Reddy. 1988. S. V. Dushkova, M. S. Falk, P. J. Young, K. A. Hairs, W. E. Ho, H. T. Macao, P. F. Robertson, G. Stock, D. Sack, T. Wain, A. W., Boong Mad Chem. Lett. 2000, 10: 715-717.
24. Rubinstein, L. V., Shmelkner, R. H., Paul, K. D., Simon, R. M., Tawil, S., Sheehan, P., Rubinstein, D. A., J. Nat. Can. Inst. 1990, 82(12): 1113-8.

- Bioluminescent replacement of the phosphate group in SAPs by hydrolytically more labile triazolidone moieties afforded a novel series of cytotoxic agents for prostate cancer.
- Removal of the lipophilic alkyl chain or replacement by hydrophobic aryl groups decreases the biological activity.
- 2-Aryl-9-oxo-1,2,3,4-tetrahydro-1H-benzotriazin-4-ylidene derivatives of various sizes are sensitive to cytotoxicity.
- Sulfur oxidation is tolerated as compounds 22 and 23 showed good cytotoxicity.



Synthesis and biological evaluation of novel cytotoxic phospholipids for prostate cancer[☆]

Veeresa Gududuru,^a Eunju Hurh,^b Gangadhar G. Durgam,^a Seoung Soo Hong,^a
Vineet M. Sardar,^a Huiping Xu,^b James T. Dalton^b and Duane D. Miller^{a,*}

^aDepartment of Pharmaceutical Sciences, College of Pharmacy, University of Tennessee, Memphis, TN 38163, USA

^bDivision of Pharmaceutics, College of Pharmacy, The Ohio State University, Columbus, OH 43210, USA

Received 25 March 2004; revised 13 July 2004; accepted 14 July 2004

Available online 13 August 2004

Abstract—We describe herein synthesis, SAR, and biological evaluation of a novel series of cytotoxic serine amide phosphates (SAPs) for prostate cancer. These compounds were tested for their cytotoxicity in five human prostate cancer cell lines (DU-145, PC-3, LNCaP, PPC-1, and TSU), and in CHO and RH7777 cells (negative controls). Comparison of anticancer effects of these compounds with a standard chemotherapeutic agent 5-fluorouracil shows that they are very effective in killing prostate cancer cells with low micromolar cytotoxicity and provide us a new lead for the development of drugs for prostate cancer.

© 2004 Elsevier Ltd. All rights reserved.

Prostate cancer is the most common malignancy affecting men and is the second-leading cause of cancer deaths in the US.¹ The risk of developing prostate cancer is associated with age,² ethnicity,² family history,^{3,4} diet,⁵ and other factors. Treatment for prostate cancer depends on the stage at which cancer is found and the age and health status of the patient. Clinically, localized disease is potentially curable⁶ with standard surgery and/or radiation therapy. Standard treatment involves either removal of the entire prostate gland (radical prostatectomy) or radiation therapy aimed at the pelvic area. However, almost half of the men initially diagnosed with local disease are found to have tumors, which have advanced to the periprostatic area or beyond at the time of surgery. A variety of chemotherapeutic agents⁷ are used alone or in combination with radiotherapy to treat the advanced disease. None of the conventional approaches to cancer therapy have proven to be highly successful for prostate cancer.

One promising drug development strategy for prostate cancer involves identifying and testing agents that interfere with growth factors and other molecules involved in the cancer cell's signaling pathways. Lysophosphatidic acid^{8,9} (1, LPA) is a natural glycerophospholipid that possesses a range of biological actions and is the best characterized member of the phospholipid growth factors (PLGFs) family. LPA elicits its effects via multiple subtypes of membrane spanning G protein-coupled receptors (GPCR) that include the EDG and PSP family of receptors. The most prominent effects of LPA include stimulation of cell proliferation¹⁰ and tumor cell invasion.¹¹ LPA stimulates phospholipase D activity and cell proliferation in PC-3 cell lines.¹² One of the LPA receptors, LPA₃, has been detected in prostate tissue.¹³ Ovarian cancer cells produce and respond to LPA.¹⁴ Moreover, vascular endothelial growth factor released from ovarian cancer cells in response to LPA has been reported to induce angiogenesis in endothelial cells.¹⁵ We found that one of the compounds (2) prepared in our laboratory inhibits LPA induced chloride currents in frog oocytes.¹⁶ Thus, we thought that it would be interesting to determine the actions of a small library of these agents in several prostate cancer cell lines. Preliminary studies¹⁷ have shown that compounds 2 and 3 are effective in killing prostate cancer cells (Fig. 1). Encouraged by these results and due to important biological effects of LPA and its implications in the pathophysiology of a variety of cancers we decided to

Keywords: Prostate cancer; LPA; New agents; Cytotoxicity.

[☆]Part of this work was presented at 225th ACS National Meeting, New Orleans, LA, March 23–27, 2003 and at 94th Annual AACR Meeting, Washington, DC, July 11–14, 2003.

*Corresponding author. Tel.: +1-901-448-6026; fax: +1-901-448-3446; e-mail: dmiller@utmem.edu

optimize the activity of SAPs for in vitro anticancer activity against prostate tumor cell lines. We report in this paper the synthesis, SAR, and in vitro cytotoxic activity of SAP derivatives against five human prostate cancer cell lines and two nontumor cell lines to determine their selectivity (Fig. 1).

The general synthesis of SAPs and serine amide alcohols (SAAs) is shown in Scheme 1. Commercially available *N*-Boc-serine (*R* or *S* form) was allowed to react with an appropriate amine in the presence of EDC/HOBt to form amide **5**. Amide **5** was treated with TFA to give serine amide alcohol (**6**). Phosphorylation of amide **5** and concurrent removal of protecting groups under hydrogenolysis conditions using Pd/C in ethanol gave **2**. During the progress of this work a report¹⁸ appeared for the synthesis of **2b**. However, according to our knowledge these type of compounds (SAPs) have never been examined for prostate cancer therapy. We synthesized unsaturated analogues **9** and **11** by similar procedures as shown in Scheme 2. Serine diamide phosphates (SDAPs) and other amine derivatives were synthesized starting from *O*-benzyl *N*-Boc-serine following the earlier procedures (Scheme 3). LAH mediated reduction of compound **5e** gave long chain *N*-alkyl amino

alcohols **17** and **18** (Scheme 4). Compound **20**, which has an ethanolamine amide backbone rather than the serine amide backbone was synthesized according to the reported procedure.¹⁹

All compounds were characterized by ¹H and ¹³C NMR, mass spectroscopy and, in certain cases, elemental analysis.²⁰

We examined the cytotoxicity of synthesized compounds in five human prostate cancer cell lines (DU-145, PC-3, LNCaP, PPC-1, and TSU) and in two negative control cell lines (CHO and RH7777) using the sulforhodamine B (SRB) assay.²¹ Cells were exposed to a wide range of concentrations (0–100 μM) of the particular compound for 96 h in 96-well plates. Cells were fixed with 10% trichloroacetic acid, washed five times with water. The plates were air dried overnight and fixed cells were stained with SRB solution. The cellular protein-bound SRB was measured at 540 nm using a plate reader. Cell numbers at the end of the treatment were measured. IC₅₀ (i.e., concentration that inhibited cell growth by 50% of untreated control) values were obtained by non-linear regression analysis using WinNonlin. For comparative purposes and to understand the degree of

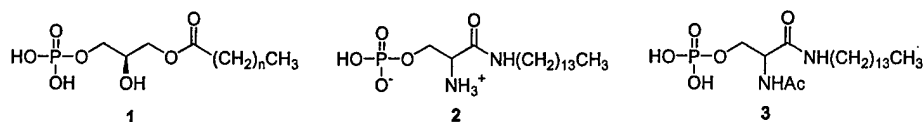
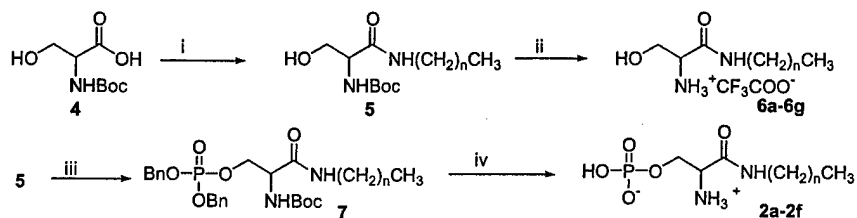
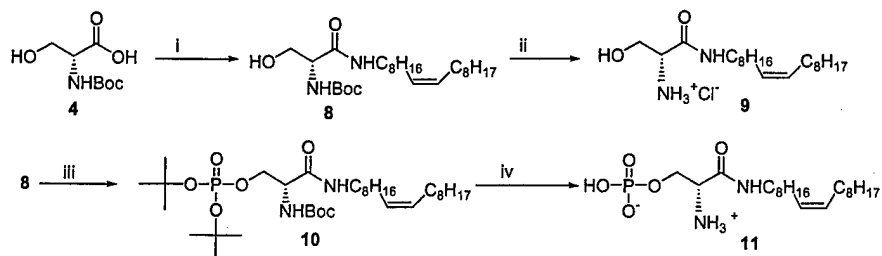


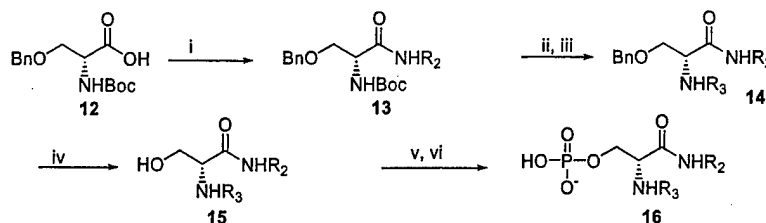
Figure 1. Structures of LPA and SAPs.



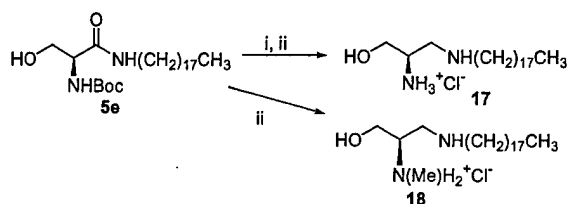
Scheme 1. Reagents and conditions: (i) CH₃(CH₂)_nNH₂, EDC, HOBt, CH₂Cl₂, rt, 5 h; (ii) TFA, CH₂Cl₂, rt, 0.5 h; (iii) tetrazole, dibenzyl diisopropylphosphoramidite, CH₂Cl₂, rt, 0.5 h, H₂O₂, rt, 0.5 h; (iv) H₂, 10% Pd/C, EtOH, rt, 3 h.



Scheme 2. Reagents and conditions: (i) C₈H₁₇(CH:CH)C₈H₁₆NH₂, EDC, HOBt, CH₂Cl₂, rt, 5 h; (ii) 2 M HCl/Et₂O, rt, overnight; (iii) tetrazole, di-*tert*-butyl diisopropylphosphoramidite, CH₂Cl₂, rt, 0.5 h, H₂O₂, rt, 0.5 h; (iv) TFA, CH₂Cl₂, rt, 0.5 h.



Scheme 3. Reagents and conditions: (i) R_2NH_2 , EDC, HOBT, CH_2Cl_2 , rt, 5h; (ii) TFA, CH_2Cl_2 , rt, 0.5h; (iii) TEA, R_3SO_2Cl or R_3NCO or R_3COCl ; (iv) H_2 , 10% Pd/C, EtOH, rt, 3h; (v) tetrazole, dibenzyl diisopropylphosphoramidite, CH_2Cl_2 , rt, 0.5h, H_2O_2 , rt, 0.5h; (vi) H_2 , 10% Pd/C, EtOH, rt, 3h.



Scheme 4. Reagents and conditions: (i) TFA, CH_2Cl_2 , rt, 0.5h (ii) (a) LAH, Et_2O , reflux, 7h; (b) HCl.

cytotoxicity we tested 5-fluorouracil against all five prostate cancer cell lines. The results are summarized in Table 1.

From the cytotoxicity data it is clear that most of the compounds tested showed good anticancer activity against all five prostate cancer cell lines. It is noteworthy, to mention that serine amide alcohols (**6b,e,f**) without a phosphate group are as effective as SAPs. A direct relationship was observed between length of the alkyl chain and cytotoxicity of the tested compounds. Accordingly, all of these compounds showed an alkyl chain length dependent cytotoxicity. Compounds with shorter alkyl chains (**2a**, **6b**, **15d**, **16d**) are less cytotoxic than analogues with longer alkyl chains (see Table 1). Compound **2f** emerged as one of the most potent SAPs tested so far with an IC_{50} of $1.8\mu M$ against PPC-1 cell line. However, serine amide alcohols are more potent than corresponding SAPs when the alkyl chain length is below 18C, but no significant difference in the cytotoxicity is observed between serine amide alcohols and SAPs with alkyl chain more than 18C.

IC_{50} values for enantiomers of serine amide alcohols (**6c,d**) and SAPs (**2b,c**) are approximately equivalent, which suggests that chirality is not important for the antiproliferative activity of these compounds in prostate cancer. Introduction of a double bond in the alkyl chain lowered the potency of both serine amide alcohol **9** and SAP **11**.

To understand the importance of the amine functionality we derivatized the amine group to the corresponding Set B amide, sulfonamide and urea derivatives. Serine diamide phosphate **16d** with a shorter alkyl chains failed to demonstrate cytotoxicity at concentration below $100\mu M$ in four prostate cancer cell lines except TSU

prostate cell line. The inhibitory activity of sulfonamide derivatives **15b** and **16b** and urea derivative **15c** in all five prostate cancer cell lines showed a general decreasing trend suggesting that derivatization of C2 amine group is not tolerable for their ability to kill prostate cancer cells.

To further investigate the extent of structural tolerance permitted in the serine amide backbone region, we replaced the serine amide group with simple ethanolamine amide by synthesizing compounds **19** and **20**. However, these ethanolamine amide analogues were less potent and particularly compound **19** did not show any activity against DU-145, PC-3, and LNCaP prostate cancer cell lines.

When the amide group in serine amide alcohols was reduced to produce long chain *N*-alkyl amino alcohols **17** and **18**, these analogues retained cytotoxicity and were very effective in killing prostate cancer cell lines with low micromolar cytotoxicity. To determine the selectivity, several of synthesized compounds were also examined for their cytotoxicity in CHO and RH7777 cells as negative controls. Many of the potent compounds showed similar cytotoxicity and were nonselective in their action against prostate cancer cell lines and non-tumor negative control cells.

In summary we have shown that SAPs and SAAs, derivatives of LPA, represent a novel class of cytotoxic phospholipids for prostate cancer. We have designed and synthesized a number of SAP derivatives and evaluated for their inhibitory activity toward the growth of human prostate cancer cell lines. Several of these, such as **2f**, **17**, and **18** are potent inhibitors of prostate tumor cell proliferation at low micromolar cytotoxicity. Despite their high cytotoxicity, the same compounds were non selective against nontumor CHO cells and receptor-negative RH7777 cells. This initial report suggests that further optimization is necessary to increase the selectivity. Efforts are in progress in our laboratory to enhance potency and selectivity of this class of compounds for the treatment of prostate cancer.

Acknowledgements

This research was supported by a Grant from the Department of Defense (DAMD17-01-1-083).

Table 1. Anti-proliferative effects of synthesized compounds in prostate cancer and negative control cell lines

Set	Compound (chirality)	IC ₅₀ (μM)									
		R ₁	R ₂	R ₃	CHO ^a	RH7777 ^a	DU-145 ^b	PC-3 ^b	LNCaP ^b	PPC-1 ^b	TSP ^b
A	2a (2R)	PO ₃ H	C ₁₀ H ₂₁	—	ND	ND	50.2	36.0	44.7	22.1	31.5
	2b (2R)	PO ₃ H	C ₁₄ H ₂₉	—	ND	ND	20.6	>50	10.1	>10	>10
	2c (2S)	PO ₃ H	C ₁₄ H ₂₉	—	ND	ND	32.0	>50	19.7	>10	>10
	2d (2R)	PO ₃ H	C ₁₈ H ₃₇	—	ND	ND	11.7	19.1	7.2	5.6	4.8
	2e (2R)	PO ₃ H	C ₁₉ H ₃₉	—	3.7	ND	5.7	15.3	5.8	1.8	5.0
	2f (2S)	PO ₃ H	C ₂₀ H ₄₁	—	7.8	ND	10.8	>20	3.6	1.8	11.1
	6a (2S)	H	C ₈ H ₁₇	—	>100	ND	>100	>100	>100	>100	>100
	6b (2R)	H	C ₁₀ H ₂₁	—	ND	ND	52.2	35.0	31.0	15.9	26.0
	6c (2R)	H	C ₁₄ H ₂₉	—	ND	ND	8.2	10.2	8.1	6.3	7.5
	6d (2S)	H	C ₁₄ H ₂₉	—	ND	ND	6.9	10.3	10.0	6.2	9.2
	6e (2R)	H	C ₁₈ H ₃₇	—	2.5	2.6	5.4	5.3	3.8	2.2	4.4
B	6f (2R)	H	C ₁₈ H ₃₇	—	2.4	3.2	5.1	5.3	5.3	1.8	3.9
	6g (2S)	H	C ₂₀ H ₄₁	—	4.1	ND	7.0	6.6	3.9	2.6	6.6
	9 (2S)	H	C ₈ H ₁₇ -CH:CH-C ₈ H ₁₆	—	5.2	6.8	6.9	5.9	6.6	5.1	5.5
	11 (2S)	PO ₃ H	C ₈ H ₁₇ -CH:CH-C ₈ H ₁₆	—	11.9	28.6	16.0	39.2	12.2	21.1	12.4
	14a (2S)	OBn	C ₁₈ H ₃₇	H	3.0	9.9	11.2	6.2	10.9	2.9	6.8
	14b (2S)	OBn	C ₁₈ H ₃₇	SO ₂ Me	>50	>50	>50	47.3	Not active	16.7	>50
	14c (2S)	OBn	C ₁₈ H ₃₇	CO NH Ph (3,5-difluoro)	18.5	>20	20	>20	>20	>20	15.9
	14d (2S)	OBn	C ₈ H ₁₇	COC ₇ H ₁₅	9.2	12.9	22.9	31.3	35.0	4.0	10.0
	15b (2S)	H	C ₁₈ H ₃₇	SO ₂ Me	12.9	9.2	23.1	13.6	16.0	10.2	20.5
	15c (2S)	H	C ₁₈ H ₃₇	CO NH Ph (3,5-difluoro)	20	>20	20	>20	>20	>20	15.3
	15d (2S)	H	C ₈ H ₁₇	COC ₇ H ₁₅	>100	ND	>100	81.5	>100	81.2	93.8
C	16b (2S)	PO ₃ H	C ₁₈ H ₃₇	SO ₂ Me	>50	50	43.2	>50	15.1	17.8	35.7
	16d (2S)	PO ₃ H	C ₈ H ₁₇	COC ₇ H ₁₅	>100	>100	>100	>100	Not active	>100	79.0
	17 (2R)	H	C ₁₈ H ₃₇	H	2.2	2.9	4.1	2.6	5.1	1.9	2.2
	18 (2R)	H	C ₁₈ H ₃₇	Me	1.7	2.5	3.2	2.4	3.3	1.6	1.1
D	19	H	C ₈ H ₁₇ -CH:CH-C ₈ H ₁₆	—	>20	>20	Not active	Not active	Not active	>20	Not active
	20	PO ₃ H	C ₈ H ₁₇ -CH:CH-C ₈ H ₁₆	—	>50	>50	>50	>50	Not active	50	>50
5-FU		—	—	—	—	—	11.9	12.0	4.9	6.4	3.6

^a Control cell lines.^b Prostate cancer cell lines.

References and notes

- Greenlee, R. T.; Murray, T.; Hill-Harmon, M. B.; Thun, M. J. *Cancer statistics. CA-Cancer J. Clin.* **2001**, *51*, 15.
- Cancer Facts Figures*; American Cancer Society: Atlanta, GA, 2003.
- Steinberg, G. D.; Carter, B. S.; Beaty, T. H.; Childs, B.; Walsh, P. C. *Prostate* **1990**, *17*, 337.
- Bratt, O. J. *J. Urol.* **2002**, *168*, 906.
- Whittemore, A.; Kolonel, L. N.; Wu, A. H.; John, E. M.; Gallagher, R. P.; Howe, G. R.; Burch, J. D.; Hankin, J.; Dreon, D. M.; West, D. W. *J. Natl. Cancer Inst.* **1995**, *87*, 652.
- Frydenberg, M.; Stricker, P. D.; Kaye, K. W. *Lancet* **1997**, *349*, 1681.
- Beedassy, A.; Cardi, G. *Semin. Oncol.* **1999**, *26*, 428.
- Jalink, K.; Hordijk, P. L.; Moolenaar, W. H. *Biochim. Biophys. Acta* **1994**, *1198*, 185.
- Tokumura, A. *Prog. Lipid Res.* **1995**, *34*, 151.
- Zhou, D.; Luini, W.; Bernasconi, S.; Diomedea, L.; Salmona, M.; Mantovani, A.; Sozzani, S. *J. Biol. Chem.* **1995**, *270*, 25549.
- Imamura, F.; Horai, T.; Mukai, M.; Shinkai, K.; Sawada, M.; Aakedo, H. *Biochem. Biophys. Res. Commun.* **1993**, *193*, 497.
- Qi, C.; Park, J. H.; Gibbs, T. C.; Shirley, D. W.; Bradshaw, C. D.; Ella, K. M.; Meier, K. E. *J. Cell. Physiol.* **1998**, *174*, 261.
- Daaka, Y. *Biochim. Biophys. Acta* **2002**, *1582*, 265.
- Shen, Z.; Belinson, J.; Morton, R. E.; Xu, Y. *Gynecol. Oncol.* **1998**, *71*, 364.
- Hu, Y. L.; Tee, M. K.; Goetzl, E. J.; Auersperg, N.; Mills, G. B.; Ferrara, N.; Jaffe, R. B. *J. Natl. Cancer Inst.* **2001**, *93*, 762.
- Sardar, V. M.; Bao, J.; Virag, T.; Jennings, L. K.; Tigyi, G.; Miller, D. D. *Abstracts of Papers*, 219th National Meeting of the American Chemical Society, San Francisco, CA 2000.
- Miller, D. D.; Tigyi, G.; Dalton, J. T.; Sardar, V. M.; Elrod, D. B.; Xu, H.; Baker, D. L.; Wang, D.; Karoly, L.; Fischer, D. J.; Virag, T.; Nusser, N. U.S. Patent. 811,838, 2003.
- Lim, H. S.; Oh, Y. S.; Suh, P. G.; Chung, S. K. *Bioorg. Med. Chem. Lett.* **2003**, *13*, 237.
- Lynch, K. R.; Hopper, D. W.; Carlisle, S. J.; Catalano, J. G.; Zhang, M.; MacDonald, T. L. *Mol. Pharmacol.* **1997**, *52*, 75.
- All synthesized compounds were purified by column chromatography and purity was confirmed by elemental analysis and HPLC. Characteristic data for some compounds is given below.
Compound **2e**: ^1H NMR (300 MHz, $\text{CF}_3\text{CO}_2\text{D}$) δ 0.77 (br s, 3H), 1.20 (br s, 32H), 1.53 (br s, 2H), 3.32–3.33 (m, 2H), 4.50 (br s, 1H), 4.67–4.72 (m, 2H); ^{13}C NMR (300 MHz, $\text{CF}_3\text{CO}_2\text{D}$) δ 11.92, 21.61, 25.78, 27.65, 28.13, 28.46, 28.49, 28.62, 28.67, 28.74, 31.0, 40.71, 54.27, 63.54, 164.99; MS (ESI) m/z 449 [M–H]. Anal. Calcd for $\text{C}_{22}\text{H}_{47}\text{N}_2\text{O}_5\text{P} \cdot 0.5\text{EtOH}$: C, 58.64; H, 10.51; N, 6.22. Found: C, 58.33; H, 10.64; N, 5.91.
Compound **16b**: ^1H NMR (300 MHz, $\text{CF}_3\text{CO}_2\text{D}$) δ 0.79 (t, $J = 6.6\text{ Hz}$, 3H), 1.22 (br s, 30H), 1.56 (m, 2H), 3.20 (s, 3H), 3.35 (t, $J = 6.9\text{ Hz}$, 2H), 4.50–4.70 (br m, 3H); ^{13}C NMR (300 MHz, $\text{CF}_3\text{CO}_2\text{D}$) δ 11.77, 21.50, 25.69, 27.63, 28.05, 28.35, 28.42, 28.51, 28.56, 28.63, 30.97, 39.70, 40.55, 56.04, 67.72, 66.73, 169.85; MS (ESI) m/z 513.2 [M–H].
Compound **18**: ^1H NMR (300 MHz, $\text{DMSO}-d_6$) δ 0.83 (t, $J = 6.9\text{ Hz}$, 3H), 1.23 (br s, 32H), 2.66 (br s, 3H), 2.92 (m, 2H), 3.2 (m, 2H), 3.52 (br s, 1H), 3.62–3.82 (m, 2H), 9.11 (br s, 1H), 9.35 (m, 2H); ^{13}C NMR (300 MHz, $\text{DMSO}-d_6$) δ 13.85, 21.99, 25.26, 25.87, 28.44, 28.6, 28.73, 28.87, 28.9, 28.95, 30.0, 31.2, 44.39, 47.33, 47.45, 56.16, 57.05; MS (ESI) m/z 357.5 [M+H].
Compound **20**: The spectroscopic properties of this compound were inconsistent with the assigned structure reported in the literature.¹⁹
- Rubinstein, L. V.; Shoemaker, R. H.; Paull, K. D.; Simon, R. M.; Tosini, S.; Skehan, P.; Scudiero, D. A.; Monks, A.; Boyd, M. R. *J. Natl. Cancer Inst.* **1990**, *82*, 1113.



Synthesis and antiproliferative activity of 2-aryl-4-oxo-thiazolidin-3-yl-amides for prostate cancer[☆]

Veeresa Gududuru,^a Eunju Hurh,^b James T. Dalton^b and Duane D. Miller^{a,*}

^aDepartment of Pharmaceutical Sciences, College of Pharmacy, University of Tennessee Health Science Center, Memphis, TN 38163, USA

^bDivision of Pharmaceutics, College of Pharmacy, The Ohio State University, Columbus, OH 43210, USA

Received 22 July 2004; revised 11 August 2004; accepted 11 August 2004

Available online 17 September 2004

Abstract—We have previously described serine amide phosphates (SAPs) as a novel class of cytotoxic agents for prostate cancer. Several of them showed potent cytotoxicity against human prostate cancer cell lines, but were not selective in non-tumor cells. To improve the selectivity and further enhance the potency, we designed a new series of 2-aryl-4-oxo-thiazolidin-3-yl amides. The current work describes synthesis, SAR, and biological evaluation of these compounds for their ability to inhibit the growth of prostate cancer cells. The antiproliferative effects of synthesized compounds were examined in five human prostate cancer cell lines (DU-145, PC-3, LNCaP, PPC-1, and TSU), and in RH7777 cells (negative controls). From this study, three potent compounds (**8**, **20**, and **21**) have been detected, which are effective in killing prostate cancer cells with improved selectivity compared to SAPs. © 2004 Published by Elsevier Ltd.

Prostate cancer accounts for 33% of all newly diagnosed malignancies among men in the United States.¹ According to the American Cancer Society,² an estimated 230,110 men will be diagnosed with prostate cancer in 2004, and 29,900 men will die of it. The incidence of prostate cancer varies worldwide, with the highest rates found in the United States, Canada, and Scandinavia, and the lowest rates found in China and other parts of Asia.^{3,4} These differences are caused by genetic susceptibility, exposure to unknown external risk factor, or differences in health care and cancer registration, or even a combination of these factors.⁴

Cancer of the prostate is multifocal and it is commonly observed that the cancerous gland contains multiple independent lesions, suggesting the heterogeneity of the disease.⁵ Determinants responsible for the pathologic growth of the prostate remain poorly understood, although steroidal androgens and peptide growth factors have been implicated.^{6,7} As long as the cancer is

confined to the prostate, it can be successfully controlled by surgery or radiation, but in metastatic disease, few options are available beyond androgen ablation,⁸ the mainstay of treatment in the case of lymph node involvement or disseminated loci. Once tumor cells have become hormone refractory, the standard cytotoxic agents are marginally effective in slowing disease progression, although they do provide some degree of palliative relief. Current chemotherapeutic regimens, typically two or more agents, afford response rates in the range of only 20–30%.^{9,10}

We have endeavored to address the need for improved antitumor therapy by means of a novel approach, and a recent report from our laboratory details the development of serine amide phosphates (SAPs), derivatives of lysophosphatidic acid (LPA) as effective cytotoxic agents against human prostate cancer cell lines.¹¹ We showed that SAP derivatives represent a class of anti-cancer agents for the treatment of prostate cancer and several of these were potent inhibitors of prostate tumor cell proliferation at low micromolar concentrations.¹¹ Despite their high cytotoxicity, the same compounds were not selective against non-tumor CHO cells and LPA receptor negative RH7777 cells. We also hypothesize that the phosphate group in SAPs is susceptible to hydrolysis, as the phosphate moiety is readily hydrolyzed by the action of lipid phosphate

Keywords: Prostate cancer; Lysophosphatidic acid; Phosphate mimics; Thiazolidinones; Antiproliferative effect.

[☆] This work was presented at the 31st MALTO Meeting, Memphis, TN, May 16–18, 2004.

* Corresponding author. Tel.: +1 901 448 6026; fax: +1 901 448 3446; e-mail: dmiller@utmem.edu

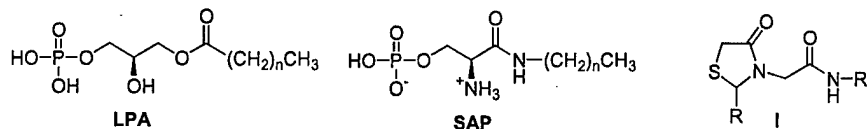
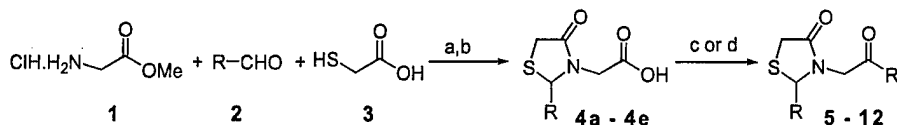


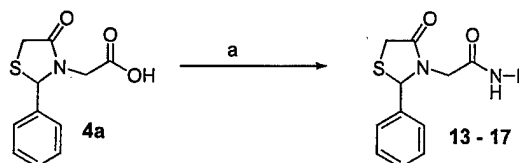
Figure 1.

Scheme 1. Reagents: (a) toluene, Dean–Stark; (b) NaOH, MeOH; (c) CH₃(CH₂)_nNH₂, EDC, HOBT, CH₂Cl₂; (d) (COCl)₂, benzene, NH₃, MeOH.

phosphatases.^{12–14} The biomimetic replacement of phosphate group by a hydrolytically more stable pharmacophore would be expected to prolong biological activity by altering pharmacokinetics and metabolism.

Andres et al. have postulated that 4-thiazolidinones may be recognized as phosphate mimics, and using this scaffold they synthesized and evaluated some 4-thiazolidinones for their ability to inhibit the bacterial enzyme MurB.¹⁵ Based on this hypothesis, we decided to explore the 4-thiazolidinone pharmacophore as a biomimetic replacement for the phosphate group. This strategic modification would be expected to enhance the physicochemical, pharmacokinetic, and antiproliferative properties and result in highly potent and selective anticancer agents for prostate cancer. To this end, we designed a new series of thiazolidinone derivatives as shown in Figure 1. In this paper we report the synthesis, structure–activity relationship, and antiproliferative activity of type I compounds (Fig. 1) in five human prostate cancer cell lines (DU-145, PC-3, LNCaP, PPC-1, and TSU).

The synthesis of thiazolidinone derivatives (5–12) utilized straightforward chemistry as shown in Scheme 1. Various 4-thiazolidinones were synthesized following a reported procedure¹⁶ of condensing mercaptoacetic

Scheme 2. Reagents: (a) R–NCO, DMAP, CH₂Cl₂.

acid, glycine methyl ester, and aromatic aldehydes in a one-pot reaction, followed by basic hydrolysis of the ester. Thiazolidinone amides were obtained by the treatment with appropriate amines in the presence of EDC/HOBt under standard conditions. Compound 5 that has no side chain was synthesized from the corresponding acid as shown in Scheme 1. Thiazolidinone amides 13–17 were synthesized by a simple and direct method,¹⁷ which involves reaction of the acid 4a with different isocyanates in the presence of a catalytic amount of DMAP (Scheme 2). Exhaustive reduction of 8 using BH₃·THF under reflux conditions gave 19 (Scheme 3). Oxidation of 8 using H₂O₂ and with KMnO₄ afforded sulfoxide (20) and sulfone (21), respectively, as shown in Scheme 3. All compounds¹⁸ were characterized by ¹H and ¹³C NMR, mass spectroscopy and, in certain cases, elemental analysis.

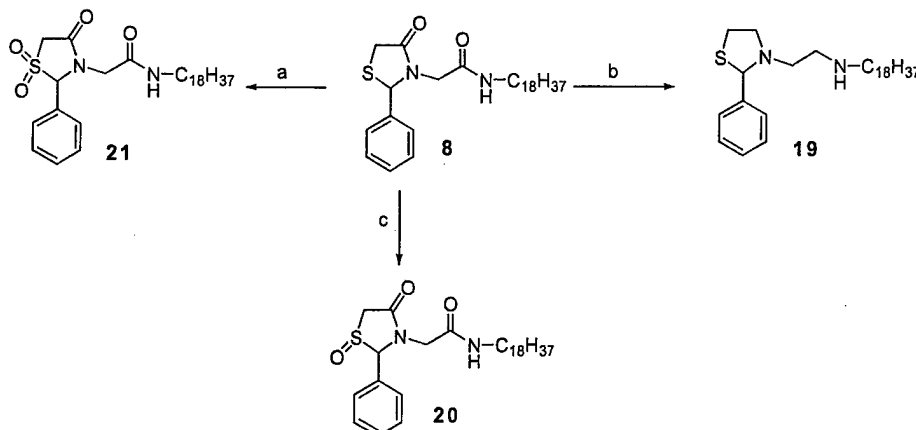
Scheme 3. Reagents: (a) KMnO₄, AcOH; (b) BH₃·THF; (c) H₂O₂, AcOH.

Table 1. Antiproliferative effects of compounds 4a–b and 5–18

Compd	IC ₅₀ (μM)							
	R	R ¹	RH 7777 ^a	DU-145 ^b	PC-3 ^b	LNCaP ^b	PPC-1 ^b	TSU ^b
4a	Ph	OH	ND	>50	>50	>50	>50	>50
4b	Biphenyl	OH	>100	>100	>100	>100	>100	>100
5	Ph	NH ₂	>100	>100	>100	>100	>100	>100
6	Ph	NHC ₁₀ H ₂₁	20.0	22.4	20.3	14.1	15.8	19.7
7	Ph	NHC ₁₄ H ₂₉	16.4	19.6	13.5	14.1	10.1	13.4
8	Ph	NHC ₁₈ H ₃₇	39.6	12.6	11.1	9.3	7.1	8.5
9	Biphenyl	NHC ₁₈ H ₃₇	>50	>50	>50	>50	>50	>50
10		NHC ₁₈ H ₃₇	>50	>50	>50	>50	>50	>50
11		NHC ₁₈ H ₃₇	31.1	14.8	12.6	11.8	10.7	17.5
12		NHC ₁₈ H ₃₇	>50	>50	>50	>50	>50	>50
13	Ph		70.9	69.0	74.1	24.1	46.2	53.2
14	Ph		25.4	16.2	18.1	14.5	13.1	16.1
15	Ph		34.9	24.0	28.6	13.2	20.5	17.2
16	Ph		>100	>100	>100	82.5	>100	60.8
17	Ph		>100	>100	>100	31.4	>100	69.9
18	Ph		>100	>100	>100	>100	>100	>100
	5-FU		ND	11.9	12.0	4.9	6.4	3.6

^a Control cell line.^b Prostate cancer cell lines.

Table 2. Antiproliferative effects of compounds 19–21

Compd	Structure	IC ₅₀ (μM)					
		RH 7777 ^a	DU-145 ^b	PC-3 ^b	LNCaP ^b	PPC-1 ^b	TSU ^b
19		>20	15.8	>20	>20	12.0	6.1
20		11.5	11.2	6.5	7.9	5.4	6.4
21		22.1	15.5	8.5	10.9	5.5	9.3
	5-FU	ND	11.9	12.0	4.9	6.4	3.6

^a Control cell line.^b Prostate cancer cell lines.

The antiproliferative activity of all the synthesized compounds has been evaluated against five human prostate cancer cell lines and in RH7777 cells (negative control) using the sulforhodamine B (SRB) assay.¹⁹ 5-Fluorouracil (5-FU) was used as reference drug. As shown in Table 1, 4-thiazolidinone carboxylic acids (**4a** and **4b**) were unable to inhibit the growth of any of the five prostate cancer cells below 50 μM. However, the corresponding amides (**6–8**) showed higher activities. It was observed that an increase in the alkyl chain length [**6** (C10), **7** (C14), and **8** (C18)] enhances the antiproliferative activity of these analogs in prostate cancer cells. Interestingly, the simple amide **5** without any long alkyl chain is not cytotoxic below 100 μM, which indicates that the absence of an alkyl side chain causes a considerable decrease in antiproliferative effect. On the other hand, replacement of the alkyl chain with various aryl side chains (**13–18**) reduced the biological activity. Among this series, **13** is moderately cytotoxic, whereas analogs **16–18** displayed poor cytotoxicity in several prostate cancer cell lines. However, it is noteworthy to mention that thiazolidinone amides (**14** and **15**), with electron-withdrawing substituents on the aryl ring showed cytotoxicity in the range of 13–29 μM against all five prostate cancer cell lines.

Thiazolidinone derivatives (**9** and **10**) with bulky biphenyl or naphthalene groups demonstrated low cytotoxicity compared to **8** (Table 1). We synthesized compounds **11** and **12** to understand the effects of aromatic ring substitution in **8**. It was observed that electron-donating substituents maintained good activity while the *ortho* electron-withdrawing substituents substantially decrease the antiproliferative activity of these derivatives (Table 1). Compound **19**, which has no amide groups, showed significantly good potency in all five prostate cancer cell lines. Notably, **20** and **21** bearing sulfoxide or sulfone moiety displayed higher cytotoxic potency comparable to that of the reference drug 5-FU against both PC-3 and PPC-1 cell lines (Table 2).

In summary, starting with the SAPs, we identified a series of novel and cytotoxic 4-thiazolidinone amides based on a 4-thiazolidinone scaffold. Among this series, we synthesized and carried out detailed structure activity relationship studies of type I compounds (Fig. 1) and evaluated their antiproliferative activity against five prostate cancer cell lines and RH7777 cells (negative controls). The cytotoxicity study shows that the antiproliferative activity is sensitive to 2-aryl ring substitutions, the length of the alkyl side chain, and the removal or replacements of the lipophilic alkyl side chain. Sulfur oxidation is well tolerated as compounds **20** and **21** showed significant cytotoxicity compared to 5-FU. This study resulted in the discovery of potent cytotoxic 4-thiazolidinones **8**, **20**, and **21**, which inhibit the growth of all five human prostate cancer cell lines (DU-145, PC-3, LNCaP, PPC-1, and TSU) with 2–5-fold lower selectivity compared to RH7777 cell line. These 4-thiazolidinone derivatives are a significant improvement on the SAP moiety in that they are less cytotoxic but demonstrated improved selectivity in non-tumor cells. However, further investigations are required to increase the potency and selectivity.

Acknowledgements

This research was supported by a grant from the Department of Defense (DAMD17-01-1-083).

References and notes

- American Cancer Society: *Cancer Facts and Figures*, 2003; American Cancer Society: Atlanta, GA, 2003.
- American Cancer Society: *Cancer Facts and Figures*, 2004.
- Quinn, M.; Babb, P. *BJU Int.* **2002**, *90*, 162.
- Gronberg, H. *Lancet* **2003**, *361*, 859.

5. Foster, C. S.; Bostwick, D. G.; Bonkhoff, H.; Damber, J. E.; van der Kwast, T.; Montironi, R.; Sakr, W. A. *Scand. J. Urol. Nephrol.* **2000**, *205*, 19.
6. Agus, D. B.; Cordon-Cardo, C.; Fox, W.; Drobnjak, M.; Koff, A.; Golde, D. W.; Scher, H. I. *J. Natl. Cancer. Inst.* **1999**, *91*, 1869.
7. Djakiew, D. *Prostate* **2000**, *42*, 150.
8. Frydenberg, M.; Stricker, P. D.; Kaye, K. W. *Lancet* **1997**, *349*, 1681.
9. Beedassy, A.; Cardi, G. *Sem. Oncol.* **1999**, *26*, 428.
10. Raghavan, D.; Koczwara, B.; Jarvis, M. *Eur. J. Cancer* **1997**, *33*, 566.
11. Gududuru, V.; Hurh, E.; Durgam, G. G.; Hong, S. S.; Sardar, V. M.; Xu, H.; Dalton, J. T.; Miller, D. D. *Bioorg. Med. Chem. Lett.* **2004**, *14*, 4919.
12. Jasinska, R.; Zhang, Q. X.; Pilquil, C.; Singh, I.; Xu, J.; Dewald, J.; Dillon, D. A.; Berthiaume, L. G.; Carman, G. M.; Waggoner, D. W.; Brindley, D. N. *Biochem. J.* **1999**, *340*, 677.
13. Xu, J.; Love, L. M.; Singh, I.; Zhang, Q. X.; Dewald, J.; Wang, D. A.; Fischer, D. J.; Tigyi, G.; Berthiaume, L. G.; Waggoner, D. W.; Brindley, D. N. *J. Biol. Chem.* **2000**, *275*, 27520.
14. Hooks, S. B.; Santos, W. L.; Im, D. S.; Heise, C. E.; Macdonald, T. L.; Lynch, K. R. *J. Biol. Chem.* **2001**, *276*, 4611.
15. Andres, C. J.; Bronson, J. J.; D'Andrea, S. V.; Deshpande, M. S.; Falk, P. J.; Young, K. A.; Harte, W. E.; Ho, H. T.; Misco, P. F.; Robertson, J. G.; Stock, D.; Sun, Y.; Walsh, A. W. *Bioorg. Med. Chem. Lett.* **2000**, *10*, 715.
16. Homes, C. P.; Chinn, J. P.; Look, C. G.; Gordon, E. M.; Gallop, M. A. *J. Org. Chem.* **1995**, *60*, 7328.
17. Schuermacher, A. C.; Hoffman, R. W. *Synthesis* **2001**, *22*, 243.
18. Compounds were obtained as mixtures of diastereomers and were used as such for the biological studies. Characteristic data for some compounds are given below. Compound 8: ^1H NMR (300 MHz, CDCl_3): δ 0.89 (t, $J = 6.0\text{ Hz}$, 3H), 1.26 (br s, 30H), 1.46 (m, 2H), 3.16–3.29 (m, 3H), 3.82 (d, $J = 1.5\text{ Hz}$, 2H), 4.20 (s, 0.5H), 4.25 (s, 0.5H), 5.83–5.85 (m, 2H), 7.27–7.41 (m, 5H); ^{13}C NMR (300 MHz, CDCl_3): δ 13.55, 22.13, 26.30, 28.69, 28.80, 28.88, 28.99, 29.03, 29.10, 29.14, 31.37, 32.13, 39.08, 45.88, 63.67, 127.05, 128.58, 128.96, 137.61, 166.30, 171.61; MS (ESI) m/z 511 $[\text{M}+\text{Na}]$. Anal. Calcd for $\text{C}_{29}\text{H}_{48}\text{N}_2\text{O}_2\text{S}$: C, 71.26; H, 9.90; N, 5.73. Found: C, 71.18; H, 10.03; N, 5.79.
- Compound 11: ^1H NMR (300 MHz, CDCl_3): δ 0.89 (t, $J = 6.0\text{ Hz}$, 3H), 1.26 (br s, 30H), 1.33 (s, 2H), 3.16–3.19 (m, 1H), 3.2–3.29 (m, 2H), 3.80 (d, $J = 0.9\text{ Hz}$, 2H), 3.83 (s, 3H), 4.16 (s, 0.5H), 4.21 (s, 0.47H), 5.82 (s, 1H), 6.9 (dd, $J = 1.8\text{ Hz}$, 2H), 7.29 (dd, $J = 1.5\text{ Hz}$, 2H); ^{13}C NMR (300 MHz, CDCl_3): δ 13.53, 22.12, 26.31, 28.70, 28.74, 28.79, 28.89, 28.99, 29.03, 29.09, 29.13, 31.36, 32.23, 39.06, 45.74, 54.79, 63.44, 128.64, 129.11, 159.97, 166.41, 171.47; MS (ESI) m/z 541 $[\text{M}+\text{Na}]$. Anal. Calcd for $\text{C}_{30}\text{H}_{50}\text{N}_2\text{O}_3\text{S}$: C, 69.45; H, 9.71; N, 5.40. Found: C, 69.30; H, 9.86; N, 5.43.
- Compound 12: ^1H NMR (300 MHz, CDCl_3): δ 3.54 (d, $J = 15.3\text{ Hz}$, 1H), 3.87 (s, 2H), 4.25 (d, $J = 15.3\text{ Hz}$, 1H), 5.88 (s, 1H), 7.10 (t, $J = 1.8\text{ Hz}$, 1H), 7.36–7.43 (m, 7H), 8.29 (s, 1H); ^{13}C NMR (300 MHz, CDCl_3): δ 32.35, 46.73, 64.40, 117.37, 123.85, 127.29, 128.74, 129.32, 134.59, 136.87, 138.61, 165.14, 172.60; MS (ESI) m/z 403 $[\text{M}+\text{Na}]$. Anal. Calcd for $\text{C}_{17}\text{H}_{14}\text{Cl}_2\text{N}_2\text{O}_2\text{S}$: C, 53.55; H, 3.70; N, 7.35. Found: C, 53.39; H, 3.47; N, 7.36.
- Compound 21: ^1H NMR (300 MHz, CDCl_3): δ 0.89 (t, $J = 6.0\text{ Hz}$, 3H), 1.26 (br s, 32H), 3.19–3.34 (m, 3H), 3.88–4.03 (dd, $J = 16.5\text{ Hz}$, 2H), 4.66 (s, 0.5H), 4.72 (s, 0.5H), 5.67 (br s, 1H), 5.95 (s, 1H), 7.38 (m, 2H), 7.50–7.53 (m, 3H); ^{13}C NMR (300 MHz, CDCl_3): δ 13.54, 22.12, 26.26, 28.66, 28.79, 28.96, 29.02, 29.09, 29.14, 31.36, 39.30, 44.35, 49.85, 81.32, 125.77, 128.43, 128.91, 130.55, 163.23, 165.30; MS (ESI) m/z 519 $[\text{M}-\text{H}]$. Anal. Calcd for $\text{C}_{29}\text{H}_{48}\text{N}_2\text{O}_4\text{S}$: C, 66.88; H, 9.29; N, 5.38. Found: C, 66.68; H, 9.27; N, 5.41.
19. Thiazolidinone derivatives were dissolved in dimethyl sulfoxide (DMSO) and serially diluted in complete growth medium to desired final concentrations at DMSO concentrations of less than 0.5%. Cells were exposed to a wide range of concentrations (0–100 μM) of the particular compound for 96 h in 96 well plates. Cells were fixed with 10% trichloroacetic acid and washed five times with water. The plates were air dried overnight and fixed cells were stained with SRB solution. The cellular protein-bound SRB was measured at 540 nm using a plate reader. Cell numbers at the end of the treatment were measured. IC_{50} (i.e., concentration that inhibited cell growth by 50% of untreated control) values were obtained by nonlinear regression analysis using WinNonlin.

Efficient Microwave Enhanced Synthesis of 4-Thiazolidinones

Veeresa Gududuru^a, Viet Nguyen^a, James T. Dalton^b and Duane D. Miller^{a*}

^aDepartment of Pharmaceutical Sciences, College of Pharmacy, University of Tennessee, Memphis, TN 38163, USA

^bDivision of Pharmaceutics, College of Pharmacy, The Ohio State University, Columbus, OH 43210, USA

Fax: 901-448-3446

E-mail: dmiller@utmem.edu

Received: The date will be inserted once the manuscript is accepted.

Abstract: A microwave enhanced, rapid, 3-component one-pot condensation method has been developed for the synthesis of 4-thiazolidinones using environmentally benign solvent ethanol in open vessels at atmospheric pressure. Applying this methodology ten different 4-thiazolidinones were synthesized in good yields.

Key words: microwave, heterocycles, condensation, 4-thiazolidinones, synthesis

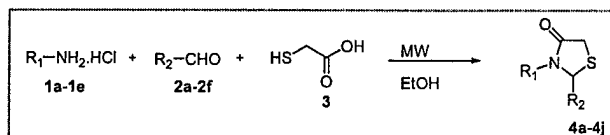
Experience has shown that compounds with biological activity are often derived from heterocyclic structures. Indeed, one of richest sources of diversity for the medicinal chemist is small heterocyclic rings, which in addition to often exhibiting biological activity, may serve as rigid scaffolds for further display of functionalities. Thiazolidinones are one such class of heterocycles, which attracted much attention as they have been reported to possess a wide range of biological activities including antifungal, antibacterial, antihistaminic, antimicrobial and anti-inflammatory activities¹.

As part of our endeavor to discover new anticancer agents we designed and synthesized highly cytotoxic thiazolidinone scaffold containing compounds for prostate cancer (undisclosed results). During this process we were seeking a rapid and efficient method for the synthesis of 4-thiazolidinones. Literature survey shows that many different protocols have been developed for the synthesis of 4-thiazolidinones. Most commonly employed methods² involve a one-pot three-component condensation of a primary amine, an aldehyde and mercaptoacetic acid with simultaneous azeotropic distillation of water formed in the reaction. Alternatively, a recent report³ describes carbodiimide (DCC) mediated three-component reaction for the synthesis of 4-thiazolidinones. In either case the reaction is believed to proceed via imine formation followed by attack of sulfur on the imine carbon and final intramolecular cyclization with the elimination of water. However, the general applicability of the above-mentioned methods are limited, as the reactions require prolonged heating with continuous removal of water, and in some cases the reaction is performed in sealed vessels in the presence of a desiccant like anhydrous ZnCl₂⁴ or sodium sulphate⁵ or molecular sieves, and the use of stoichiometric amounts of DCC. In order to circumvent these difficulties and to speed up the synthesis we focused on developing an alternate method for the synthesis of 4-thiazolidinones.

Initially introduced in 1986⁶ the chemical application of microwaves has now become an area of interest for the synthesis of a wide variety of compounds. The advantages of microwave-expedited chemical synthesis

are cleaner reactions, shorter reaction times and the ease of manipulation. Parekh⁷ has described microwave-mediated synthesis of 4-thiazolidinones. However, this method⁷ involves separate preparation of an hydrazone from the corresponding aldehyde and hydrazine, which was then mixed with thioglycolic acid and exposed to high power microwave irradiation.

In this communication we report microwave enhanced three-component one-pot condensation of primary amine, an aldehyde and mercaptoacetic acid for the synthesis of a diverse set of 4-thiazolidinones (Scheme 1).



Scheme 1

A range of primary amines and aldehydes were condensed with mercaptoacetic acid in the presence of Hunig's base and molecular sieves under microwave irradiation (Figure 1). To optimize the method, initially we examined the condensation in toluene and observed that desired product was formed in low yield. Furthermore, all our attempts to improve the yield at elevated temperature, microwave power and longer reaction times were met with unsuccessful results. This may be probably due to poor microwave absorbing nature of toluene. In microwave mediated organic synthesis one of the most important characteristics of a solvent is its polarity. The more polar a solvent, the greater its ability to couple with the microwave energy, the faster the temperature of the reaction mixture increases that leads to faster reaction rates. To increase the efficiency we decided to perform the condensation in a more polar and high microwave absorbing solvent like ethanol. However, most of the reported methods² involve use of either high boiling hydrocarbons like toluene or benzene, or aprotic solvent tetrahydrofuran for this type of condensations. To check the feasibility of condensation in a protic solvent, a pilot experiment was carried out using glycine, benzaldehyde and mercaptoacetic acid (Table 1, entry 1) in ethanol and observed that the reaction proceeded uneventfully forming the desired product in good yield. Interestingly, no product was formed when the reaction was carried out in ethanol in the absence of microwaves.

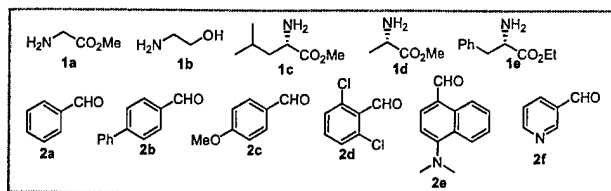


Figure 1. Various amines and aldehydes used for the condensation

Encouraged by this result and to understand the general applicability of this protocol, we have synthesized a variety of 4-thiazolidinones. For these purpose five different amines, five different aldehydes were selected and condensed with mercaptoacetic acid (Table 1). With a chiral center in the amine component (Table 1, entries 8-10) as one might expect, formation of diastereomeric products was observed. The diastereomeric ratio was determined by NMR and LC-MS analysis {4h (1:1.8), 4i (1:1), 4j (1:1.7)}. It was observed that the ratios of reactants at 1:2:3 for amine, aldehyde and mercaptoacetic acid, respectively gave best yields. This is in agreement with the earlier observation by Holmes et al.² Accordingly, the optimized procedure⁸ involves microwave irradiation (power: 100 W) of a mixture of amine, aldehyde and mercapto acetic acid (1:2:3) in presence of 1.25 equiv of Hunig's base in ethanol at 120°C for 30 min at atmospheric pressure and after

standard workup gave the desired 4-thiazolidinones in good to high yields (Table 1).

In conclusion, we have developed a convenient three-component one-pot microwave rate enhanced efficient method for the synthesis of 4-thiazolidinones. It is noteworthy to mention that all reactions were carried out at atmospheric pressure in open vessels using environmentally benign solvent ethanol. The simplicity of this short procedure and generally satisfactory yields render this method particularly attractive for the rapid synthesis of 4-thiazolidinones.

Table 1 Isolated Yields of 4-Thiazolidinones

Entry	Amine.HCl	Aldehyde	Mercapto acid	4-Thiazolidinone	%Yield
1	1a	2a	3	4a	80
2	1a	2b	3	4b	83
3	1a	2c	3	4c	90
4	1a	2d	3	4d	65
5	1a	2e	3	4e	80
6	1a	2f	3	4f	91
7	1b	2a	3	4g	76
8	1c	2a	3	4h	55
9	1d	2a	3	4i	68
10	1e	2a	3	4j	63

Acknowledgment

This research was supported by a grant from the Department of Defense (DAMD17-01-1-083)

References and Notes

- (1) (a) Newkome, G. R.; Nayak, A. *Advances in Heterocyclic Chemistry*, Vol. 25; Academic Press: New York, 1979, pp 83. (b) Singh, S. P.; Parmar, S. S.; Raman, K.; Stenberg, V. I. *Chem. Rev.* 1981, 81, 175.
- (2) Homes, C. P.; Chinn, J. P.; Look, C. G.; Gordon, E. M.; Gallop, M. A. *J. Org. Chem.* 1995, 60, 7328.
- (3) Srivatsava, T.; Haq, W.; Katti, S. B. *Tetrahedron.* 2002, 58, 7619.
- (4) Srivatsava, S. K.; Srivatsava, S. L.; Srivatsava, S. D. J. *Indian Chem. Soc.* 2000, 77, 104.
- (5) Sharma, R. C.; Kumar, D. J. *Indian Chem. Soc.* 2000, 77, 492.
- (6) Gedye, R.; Smith, F.; Westaway, K.; Ali, H.; Baldisera, L.; Laberge, L.; Rousell, J. *Tetrahedron Lett.* 1986, 27, 279.
- (7) Khatri, B. L.; Trivedi, A. M.; Sodha, V. A.; Hirpara, H. M.; Parekh, H. H. *Indian J. Het Chem.* 2002, 12, 175.

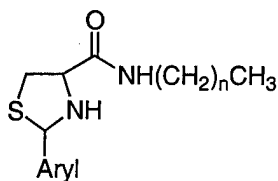
- (8) Typical procedure for the synthesis of 4-thiazolidinones: A mixture of Glycine methyl ester hydrochloride (1a, 0.5 g, 4 mmol), aldehyde (2e, 1.66 g, 8.3 mmol), mercaptoacetic acid (0.83 mL, 12 mmol), diisopropylethylamine (0.85 mL, 4.83 mmol), and molecular sieves (4A°, 0.1 g) in ethanol (10 mL) was irradiated with microwaves (power: 100W) at 120° C for 30 min, following which the sample was cooled using compressed air. The reaction mixture was diluted with CHCl₃ (75 mL), sequentially washed with satd. NaHCO₃, water, brine, dried (Na₂SO₄) and solvent was removed in vacuo to get crude product that was purified by column chromatography (silica gel, hexanes-ethyl acetate) to afford 4e (1 g, 80%). ¹H NMR (300 MHz, CDCl₃) δ 2.85-2.86 (m, 1H), 2.92 (s, 6H), 3.5-3.63 (s, 3H), 3.83 (bs, 2H), 4.64 (d, J = 17.1 Hz, 1H), 6.67 (bs, 0.6 H), 7.07 (bs, 0.7H), 7.34 (d, J = 9 Hz, 1H), 7.55 (d, J = 3.3 Hz, 2H), 7.90 (bs, 1H), 8.31 (m, 1H); ¹³C NMR (300 MHz, CDCl₃) δ 31.94, 43.75, 44.53, 51.76, 58.47, 76.72, 112.97, 121.63, 122.69, 124.83, 124.94, 126.18, 131.33, 168.09; MS (ESI) m/z 345 [M+H].

Table of Contents Graphic

Discovery of 2-Arylthiazolidine-4-carboxylic acid amides as a New Class of Cytotoxic Agents for Prostate Cancer

Veeresa Gududuru, Eunju Hurh, James T. Dalton, and Duane D. Miller *

*Department of Pharmaceutical Sciences, College of Pharmacy, University of Tennessee Health Science
Center, Memphis, TN 38163, Division of Pharmaceutics, College of Pharmacy, The Ohio State University,
Columbus, Ohio 43210*



Title

**Discovery of 2-Arylthiazolidine-4-carboxylic acid amides as a
New Class of Cytotoxic Agents for Prostate Cancer[¶]**

Veeresa Gududuru,[†] Eunju Hurh,[§] James T. Dalton,[§] and Duane D. Miller^{†*}

*Department of Pharmaceutical Sciences, College of Pharmacy, University of Tennessee Health Science
Center, Memphis, TN 38163, Division of Pharmaceutics, College of Pharmacy, The Ohio State University,
Columbus, Ohio 43210*

* Corresponding author. 847 Monroe Avenue, Room 227C, Memphis, TN 38163, USA.

Phone: +1-901-448-6026. Fax: +1-901-448-3446. E-mail: dmiller@utmem.edu.

[¶] Part of this work was presented at 227th ACS National Meeting, Anaheim, CA, March 28-April
1, 2004 and at 95th AACR Annual Meeting, Orlando, FL, March 27-March 31, 2004.

[†] Department of Pharmaceutical Sciences, University of Tennessee Health Science
Center.

[§] Division of Pharmaceutics, The Ohio State University.

Abstract

We showed that serine amide phosphates (SAPs), derivatives of lysophosphatidic acid (LPA) represent a class of cytotoxic phospholipids that are effective and potent in killing prostate cancer cells (Gududuru et al., *Bioorg. Med. Chem. Lett.* **2004**, *14*, 4919-4923). We examined the cytotoxicity of a large number of SAPs in different prostate cancer cell lines (DU-145, PC-3, LNCaP, PPC-1, and TSU-Pr1), and in a negative control cell line (RH7777) that lacks LPA receptor. Although many of these compounds showed significant cytotoxicity, they were non-selective. To improve the selectivity and antiproliferative activity, we designed a new series of 4-thiazolidinone amides (Gududuru et al., *Bioorg. Med. Chem. Lett.* **2004**, *14*, 5289-5293), in which the 4-thiazolidinone moiety was introduced as a phosphate mimic. However, these 4-thiazolidinone derivatives demonstrated less cytotoxicity in prostate cancer cells despite improved selectivity over RH7777 cells. To further optimize the thiazolidinone pharmacophore in terms of cytotoxicity and selectivity, we made closely related structural modifications on 4-thiazolidinone amides, which led us to the discovery of a new class of 2-arylthiazolidine-4-carboxylic acid amides. These compounds were potent cytotoxic agents with IC_{50} values in the low micromolar concentration range and demonstrated enhanced selectivity in receptor-negative cells compared to SAPs and 4-thiazolidinone amides.

Introduction

One promising drug development strategy for prostate cancer involves identifying and testing agents that interfere with growth factors and other molecules involved in the cancer cell's signaling pathways. G-protein coupled receptors (GPCRs) are a family of membrane-bound proteins that are involved in the proliferation and survival of prostate cancer cells initiated by binding of lysophospholipids (LPLs).¹⁻⁴ The importance of G protein-dependent pathways in the regulation of growth and metastasis *in vivo* is corroborated by the observation that the growth of androgen-independent prostate cancer cells in mice is attenuated by treatment with pertussis toxin, an inhibitor of Gi/o proteins.⁵ Lysophosphatidic acid (LPA) and sphingosine 1-phosphate (S1P) are lipid mediators generated via the regulated breakdown of membrane phospholipids that are known to stimulate GPCR-signaling.

LPLs bind to GPCRs encoded by the *Edg* gene family, collectively referred to as LPL receptors, to exert diverse biological effects. Lysophosphatidic acid (LPA) stimulates phospholipase D activity and PC-3 prostate cell proliferation.⁶ Further, prior studies have shown that LPA is mitogenic in prostate cancer cells and that PC-3 and DU-145 cells express LPA₁, LPA₂, and LPA₃ receptors.⁷ Advanced prostate cancers express LPL receptors and depend on phosphatidylinositol 3-kinase (PI3K) signaling for growth and progression to androgen independence.² Thus, these pathways are widely viewed as one of the most promising new approaches to cancer therapy,⁸ and provide an especially novel approach to the treatment of advanced, androgen-refractory prostate cancer. Despite the promise of this approach, there are no clinically available therapies that selectively exploit or inhibit LPA or PI3K signaling.

We have been exploring a novel series of molecules that inhibit the growth of human prostate cancer cells. In a previous contribution from our laboratory,⁹ by replacing the glycerol backbone in LPA with serine amide, effective cytotoxic agents were obtained, which showed potent cytotoxicity, comparable to that of reference drug 5-fluorouracil in five prostate cancer cell lines. However, the most potent compounds in that series of derivatives were non-selective and potently killed both prostate cancer and control cell lines. To improve the selectivity, enhance the pharmacokinetic, and antiproliferative properties, we designed a new series of 2-aryl-4-oxo-thiazolidin amides with general structure **III** (Figure 1), utilizing 4-thiazolidinone pharmacophore as a biomimetic replacement for the phosphate group.¹⁰ This strategic modification showed that the 2-arylthiazolidinone moiety is indeed quite beneficial for obtaining a new set of antiproliferative compounds with improved selectivity, but resulted in decreased potency compared to SAPs.⁹ To further optimize the structural characteristics of these compounds to selectively elicit antiproliferative activity, we made closely related, minor modifications to 2-aryl-4-oxo-thiazolidin amides as shown in Figure 1. Our current work highlights synthesis, structure activity relationship (SAR) studies, and biological evaluation of 2-arylthiazolidine-4-carboxylic acid amides (ATCAAs) for prostate cancer.

Chemistry

Compounds described in this study were prepared following straightforward chemistry.

Reaction of L-cysteine with various aldehydes under reported conditions¹¹ gave corresponding acids, which were isolated as diastereomeric mixtures. These mixtures were used directly for the formation of corresponding amides by reacting with appropriate alkyl amines using EDC/HOBt as shown in Scheme 1. All compounds thus prepared were characterized as diastereomeric mixtures (Table 1). N-Acyl and N-sulfonyl derivatives (**28** and **29**) were synthesized from **5** by standard procedures (Scheme 2). The synthesis of thiazole derivative **34** was accomplished starting from cysteine as shown in Scheme 3.

The structures of the synthesized compounds and the yields of the syntheses are presented in Table 1.

Results and Discussion

The ability of 2-aryl-thiazolidine derivatives (ATCAAs) to inhibit the growth of five human prostate cancer cell lines (DU-145, PC-3, LNCaP, PPC-1, and TSU-Pr1) was assessed using the sulforhodamine B (SRB) assay.⁹ We also included a control cell line (RH7777) that does not express LPL receptors,¹² to understand whether the antiproliferative activity of these derivatives was mediated through inhibition of LPL receptors. We first examined LPL receptor expression in these cell lines by RT-PCR to validate their use as *in vitro* models (Table 2). LPA₁ was the predominant LPL receptor expressed in these cell lines. However, LNCaP cells did not express this receptor subtype. LPA₂ was also expressed in all prostate cancer cell lines examined. Interestingly, ovarian cancer cells also demonstrated overexpression of LPA₂ compared to normal ovarian epithelial cells.⁸ PC-3 and LNCaP cells, but not DU-145 cells, expressed LPA₃, consistent with published data.⁷ None of the LPL receptors was expressed in RH7777 cells.

The diastereomeric mixtures of the target compounds **3-29** were used as such to evaluate their *in vitro* inhibitory activity against prostate cancer cell lines, and the results are summarized in Tables 3 and 4. 5-Fluorouracil was used as a reference drug for comparison. To deduce sound structure-activity relationships, IC₅₀s should on principle be determined on pure isomers. One drawback of testing mixtures of stereoisomers, unavoidable in our case, was that we could not assess how each stereoisomer affected the biological activity. On the other hand, the IC₅₀ values calculated can be used as a screening method to select promising selective cytotoxic agents and to identify the diastereomeric mixture with the most potent ability to inhibit the growth of prostate cancer cells. Many of these thiazolidine analogs were very effective in killing prostate

cancer cell lines with IC_{50} values as low as 480 nM (Table 3). Examination of the cytotoxic effects of **3-5** showed that as the chain length increased from C_7 to C_{18} , the potency also increased. However, a further increase in the alkyl chain length by one carbon unit (**6**) caused a significant loss of activity. Interestingly, the C_{14} derivative (**4**) demonstrated higher potency than **5**, but was 8-fold less selective against the RH7777 cell line. Thus, an alkyl chain with C_{18} unit was optimal for maintaining the potency and selectivity observed in this series of compounds. N-Acyl and N-sulfonyl derivatives (**28** and **29**) were significantly less cytotoxic than parent compound **5**. Replacement of the phenyl ring with an alkyl or cyclohexyl group reduced the potency (**7** and **8**) relative to the thiazolidine derivative (**5**). Introduction of a methylene spacer separating the phenyl ring and the thiazolidine ring furnished a compound **9**, which was less active than the parent compound **5**.

To understand the effect of unsaturation on potency and selectivity, and to overcome the problems associated with stereoisomers, we replaced the central thiazolidine core in **5** with a thiazole ring. However, thiazole derivative (**34**) did not show any activity below 20 μ M in both prostate and RH7777 cells, which suggests that thiazolidine ring with two chiral centers plays an important role in providing potency and selectivity. Replacements of the phenyl ring with a heterocycle, such as an indole, pyridine or furan ring was investigated by synthesizing analogs **10-12**. The furanyl derivative **12** showed equivalent cytotoxicity as **5**, but was 3-fold less selective against RH7777 cells.

The cytotoxicity data of compounds **13-27** provides a summary of a broad survey of phenyl ring substituted analogs. Examination of the IC_{50} values of these analogs demonstrates a greater tolerance for diverse substituents in the phenyl ring. In general, the most potent analogues possessed electron-donating substituents, as exemplified by

comparison of **13** and **16-18**, relative to **5**. Compound **18** is one of the most active compounds with an IC_{50} of 0.55 μ M was 38-fold more selective in PPC-1 cells compared to RH7777 cells. On the other hand, thiazolidine analogs (**19-25**), with electron-withdrawing substituents demonstrated less cytotoxicity. Comparison of the potencies of **26** and **27**, suggest that substitution of the phenyl ring with a bulky group reduces the activity.

From the LPL receptor mRNA expression studies (Table 2), it was evident that these cell lines serve as an excellent model system to explore the effects of LPL receptors in prostate cancer cell growth. Given the structural similarity of SAPs to ceramide (and the known ability of ceramide to induce apoptosis), we next determined whether the antiproliferative effects of thiazolidine analogs were mediated via apoptotic events. We examined the ability of our analogs to induce apoptosis in LNCaP, PC-3, and RH7777 cells using a quantitative sandwich ELISA¹³ that measures DNA-histone complex released during apoptosis. The enrichment factor calculated as ratio of OD405 in treated and un-treated cells provides a quantitative assessment of the degree of apoptosis induced. Initially, we used only two compounds (**4** and **5**) for this study. Apoptotic activity of analog **4** was selective in prostate cancer cells despite nonselective cytotoxicity in RH7777 negative control cells (Table 5). Analog **5** induced apoptosis in PC-3 and LNCaP cells, but to a lesser extent in PC-3 cells perhaps due to lower potency in this cell line. This data suggests that thiazolidine analogs may act as potent inducers of apoptosis and selectively kill a variety of prostate cancer cell lines.

Conclusions

2-Aryl-thiazolidine-4-carboxylic acid amides (ATCAAs) were obtained by the modification of previously reported 4-thiazolidinones. We synthesized a number of ATCAAs

and evaluated for their inhibitory activity towards the growth of human prostate cancer cell lines. Introduction of ring activating groups on the phenyl ring resulted in increasing potencies for prostate cancer cell lines leading to discovery of several new anticancer agents represented by analogues **16**, **17**, and **18** with low/sub micromolar cytotoxicity and high selectivity. From this study, compound **18** emerged as one of the most potent and selective cytotoxic agents with an IC_{50} of 0.55 μ M and 38-fold selectivity in PPC-1 cells. Further, the ability of these analogs to induce apoptosis in LNCaP and PC-3 cells provides an important clue to understand their mechanism of action, and suggests that they may have therapeutic utility in the treatment of prostate or ovarian cancer. All compounds discussed in this report have been prepared and tested as diastereomeric mixtures. Future efforts shall aim at synthesis and evaluation of pure individual stereoisomers of the most promising thiazolidines discussed above.

Experimental Section

All reagents and solvents used were reagent grade or were purified by standard methods before use. Moisture-sensitive reactions were carried under an argon atmosphere. Progress of the reactions was followed by thin-layer chromatography (TLC) analysis. Flash column chromatography was carried out using silica gel (200-425 mesh) supplied by Fisher. Melting points were measured in open capillary tubes on a Thomas-Hoover melting point apparatus and are uncorrected. All compounds were characterized by NMR and MS (ESI). ^1H NMR spectra were recorded on a Varian 300 instrument. Chemical shifts are reported as δ values relative to Me_4Si as internal standard. Mass spectra were obtained in the electrospray (ES) mode using Esquire-LC (Bruker) spectrometer. Elemental analyses were performed by Atlantic Microlab Inc. (Norcross, GA).

General Procedure for the Preparation of 3-27. A mixture of appropriate carboxylic acid (**2a-2v**, 0.3-0.5 g), EDC (1.25 eq) and HOBt (1 eq) in CH_2Cl_2 (25-50 mL) was stirred for 10 min. To this solution, appropriate alkyl amine (1 equiv) was added and stirring continued at room temperature for 6-8 h. Reaction mixture was diluted with CH_2Cl_2 (100-150 mL) and sequentially washed with water, sat. NaHCO_3 , brine and dried over Na_2SO_4 . The solvent was removed under reduced pressure to yield a crude solid, which was purified by column chromatography. The purified compounds (**3-6**, **12**, **15-18** & **27**) were converted to corresponding hydrochlorides using 2M $\text{HCl}/\text{Et}_2\text{O}$.

(2*RS*, 4*R*)-2-Phenylthiazolidine-4-carboxylic acid heptylamide Hydrochloride (3.HCl).

^1H NMR ($\text{DMSO}-d_6$) δ 8.72 (s, 1H), 7.65 (m, 2H), 7.43 (m, 3H), 5.89 (s, 0.6H), 5.84 (s, 0.4H), 4.66 (t, $J = 6.3$ Hz, 0.6H), 4.46 (t, $J = 6.9$ Hz, 0.4H), 3.55-3.71 (m, 1H), 3.24-3.34 (m, 1H), 3.13 (d, $J = 5.7$ Hz, 2H), 1.44 (m, 2H), 1.25 (s, 8H), 0.83 (t, $J = 6.9$ Hz, 3H); MS (ESI) m/z 307.10 ($\text{M}+1$).

(2*RS*, 4*R*)-2-Phenylthiazolidine-4-carboxylic acid tetradecylamide Hydrochloride (4.HCl).

^1H NMR (DMSO- d_6) δ 8.69 (m, 1H), 7.64-7.71 (m, 2H), 7.45 (m, 3H), 5.89 (s, 0.6H), 5.84 (s, 0.4H), 4.67 (t, J = 6.6 Hz, 0.6H), 4.47 (t, J = 7.2 Hz, 0.4H), 3.55-3.71 (m, 1H), 3.25-3.35 (m, 1H), 3.10-3.16 (m, 2H), 1.44 (m, 2H), 1.23 (s, 22H), 0.85 (t, J = 6.3 Hz, 3H); MS (ESI) m/z 427.30 (M+Na).

(2*RS*, 4*R*)-2-Phenylthiazolidine-4-carboxylic acid octadecylamide Hydrochloride (5.HCl).

^1H NMR (DMSO- d_6) δ 8.59 (d, J = 5.1 Hz, 1H), 7.63 (d, J = 3.9 Hz, 2H), 7.42-7.47 (m, 3H), 5.86 (s, 0.6H), 5.81 (s, 0.4H), 4.60 (t, J = 6.3 Hz, 0.6H), 4.39 (t, J = 6.9 Hz, 0.4H), 3.52-3.66 (m, 1H), 3.24-3.30 (m, 1H), 3.10-3.16 (m, 2H), 1.42 (m, 2H), 1.23 (s, 30H), 0.85 (t, J = 6.3 Hz, 3H); MS (ESI) m/z 461.50 (M+1).

(2*RS*, 4*R*)-2-Phenylthiazolidine-4-carboxylic acid nonadecylamide Hydrochloride (6.HCl).

^1H NMR (DMSO- d_6) δ 8.51 (s, 1H), 7.62 (m, 2H), 7.41-7.46 (m, 3H), 5.83 (s, 0.6H), 5.78 (s, 0.4H), 4.53 (m, 0.6H), 4.32 (m, 0.4H), 3.48-3.61 (m, 1H), 3.24-3.29 (m, 1H), 3.11-3.15 (m, 2H), 1.43 (m, 2H), 1.23 (s, 32H), 0.85 (t, J = 6.3 Hz, 3H); MS (ESI) m/z 497.40 (M+Na).

(2*RS*, 4*R*)-2-Dodecylthiazolidine-4-carboxylic acid octadecylamide (7). ^1H NMR (CDCl_3) δ 7.18 (m, 1H), 4.20-4.27 (m, 1H), 3.79 (m, 0.3H), 3.54-3.59 (m, 0.7H), 3.08-3.34 (m, 4H), 1.65-1.78 (m, 2H), 1.43-1.51 (m, 4H), 1.27 (brs, 48H), 0.89 (t, J = 6 Hz, 6H); MS (ESI) m/z 553.60 (M+1).

(2*RS*, 4*R*)-2-Cyclohexylthiazolidine-4-carboxylic acid octadecylamide (8). ^1H NMR

(CDCl_3) δ 7.17 (m, 1H), 4.10-4.20 (m, 1H), 3.76 (m, 0.3H), 3.54 (dd, J = 11.1, 3.6 Hz, 0.7H), 2.97-3.34 (m, 4H), 2.02 (m, 1H), 1.68-1.78 (m, 4H), 1.48-1.54 (m, 2H), 1.27 (brs, 36H), 0.87 (t, J = 6.9 Hz, 3H); MS (ESI) m/z 467.60 (M+1).

(2*RS*, 4*R*)-2-Benzylthiazolidine-4-carboxylic acid octadecylamide (9). ¹H NMR (CDCl₃) δ 7.28-7.33 (m, 5H), 7.03 (s, 0.7H), 6.48 (s, 0.3H), 4.55 (brs, 0.5H), 4.18 (brs, 0.5H), 3.82 (brs, 0.3H), 3.54 (dd, *J* = 11.1, 3.6 Hz, 0.7H), 2.99-3.31 (m, 6H), 1.46-1.51 (m, 2H), 1.27 (brs, 30H), 0.89 (t, *J* = 6.3 Hz, 3H); MS (ESI) *m/z* 475.50 (M+1).

(2*RS*, 4*R*)-2-(1*H*-Indol-3-yl)-thiazolidine-4-carboxylic acid octadecylamide (10).

¹H NMR (CDCl₃) δ 7.86 (m, 0.6H), 7.77 (m, 0.4H), 7.41-7.48 (m, 4H), 7.29-7.34 (m, 1H), 6.0 (s, 0.3H), 5.69 (s, 0.7H), 4.37-4.41 (m, 0.5H), 3.76 (dd, *J* = 11.1, 4.2 Hz, 0.5H), 3.23-3.52 (m, 3H), 2.79-3.04 (m, 1H), 1.43 (m, 2H), 1.27 (s, 30H), 0.89 (t, *J* = 6.6 Hz, 3H); MS (ESI) *m/z* 500.60 (M+1).

(2*RS*, 4*R*)-2-Pyridin-3-yl-thiazolidine-4-carboxylic acid octadecylamide (11). ¹H NMR (CDCl₃) δ 8.74 (d, *J* = 2.1 Hz, 1H), 8.60 (d, *J* = 4.8 Hz, 1H), 7.84 (d, *J* = 7.8 Hz, 1H), 7.31-7.36 (m, 1H), 7.08 (m, 1H), 5.44 (s, 0.5H), 5.40 (s, 0.5H), 4.28-4.35 (m, 1H), 3.72 (dd, *J* = 11.1, 4.2 Hz, 1H), 3.27-3.45 (m, 3H), 2.57 (m, 1H), 1.53-1.57 (m, 2H), 1.26 (s, 30H), 0.89 (t, *J* = 6.6 Hz, 3H); MS (ESI) *m/z* 462.40 (M+1).

(2*RS*, 4*R*)-2-Furan-3-yl-thiazolidine-4-carboxylic acid Hydrochloride (12.HCl). ¹H NMR (DMSO-*d*₆) δ 8.59 (d, *J* = 15.6 Hz, 1H), 7.89 (d, *J* = 8.1 Hz, 1H), 7.72 (s, 1H), 5.86 (s, 0.7H), 5.78 (s, 0.3H), 4.37-4.56 (m, 1H), 3.50-3.63 (m, 1H), 3.11-3.23 (m, 3H), 1.43 (m, 2H), 1.23 (s, 30H), 0.85 (t, *J* = 6.6 Hz, 3H); MS (ESI) *m/z* 451.60 (M+1).

(2*RS*, 4*R*)-2-(4-Dimethylamino-phenyl)-thiazolidine-4-carboxylic acid octadecylamide (13). ¹H NMR (CDCl₃) δ 7.34-7.41 (m, 2H), 6.70-6.74 (m, 2H), 5.57 (s, 0.3H), 5.28 (s, 0.7H), 4.34 (m, 0.7H), 3.90 (m, 0.3H), 3.69 (dd, *J* = 11.1, 4.2 Hz, 1H), 3.41-3.47 (m, 1H), 3.20-3.33 (m, 2H), 2.97 (d, *J* = 3.6 Hz, 6H), 1.48-1.55 (m, 2H), 1.27 (s, 30H), 0.89 (t, *J* = 6.3 Hz, 3H); MS (ESI) *m/z* 504.60 (M+1).

(2*RS*, 4*R*)-2-(3-Hydroxy-phenyl)-thiazolidine-4-carboxylic acid octadecylamide (14). ¹H NMR (DMSO-*d*₆) δ 8.59 (s, 1H), 7.22 (t, *J* = 6.6 Hz, 1H), 7.02 (d, *J* = 6.3 Hz, 2H), 6.82 (d, *J* = 7.5 Hz, 1H), 5.77 (s, 0.7H), 5.71 (s, 0.3H), 4.545 (m, 0.7H), 4.37 (m, 0.3H), 3.49-3.59 (m, 1H), 3.13-3.27 (m, 3H), 1.43 (brs, 2H), 1.23 (s, 30H), 0.85 (t, *J* = 6.3 Hz, 3H); MS (ESI) *m/z* 477.60 (M+1).

(2*RS*, 4*R*)-2-(4-Methoxy-phenyl)-thiazolidine-4-carboxylic acid octadecylamide

Hydrochloride (15.HCl). ¹H NMR (DMSO-*d*₆) δ 8.61 (m, 1H), 7.57 (d, *J* = 8.4 Hz, 2H), 6.98 (d, *J* = 9 Hz, 2H), 5.83 (s, 0.7H), 5.78 (s, 0.3H), 4.61 (t, *J* = 6.3 Hz, 0.7H), 4.40 (m, 0.3H), 3.77 (s, 3H), 3.51-3.70 (m, 1H), 3.22-3.31 (m, 1H), 3.11 (m, 2H), 1.43 (m, 2H), 1.23 (s, 30H), 0.84 (t, *J* = 6.6 Hz, 3H); MS (ESI) *m/z* 491.60 (M+1).

(2*RS*, 4*R*)-2-(3,4-Dimethoxy-phenyl)-thiazolidine-4-carboxylic acid octadecylamide

Hydrochloride (16.HCl). ¹H NMR (DMSO-*d*₆) δ 8.58 (m, 1H), 7.33 (d, *J* = 4.2 Hz, 1H), 7.14 (t, *J* = 7.5 Hz, 1H), 6.97 (d, *J* = 8.4 Hz, 1H), 5.81 (s, 0.8H), 5.77 (s, 0.2H), 4.62 (m, 0.7H), 4.40 (m, 0.3H), 3.78 (d, *J* = 7.8 Hz, 6H), 3.52-3.68 (m, 1H), 3.23-3.29 (m, 1H), 3.12-3.13 (m, 2H), 1.43 (m, 2H), 1.23 (s, 30H), 0.85 (t, *J* = 6.6 Hz, 3H); MS (ESI) *m/z* 521.60 (M+1).

(2*RS*, 4*R*)-2-(3,4,5-Trimethoxy-phenyl)-thiazolidine-4-carboxylic acid octadecylamide

Hydrochloride (17.HCl). ¹H NMR (DMSO-*d*₆) δ 8.59 (m, 1H), 7.01 (d, *J* = 5.7 Hz, 2H), 5.80 (s, 0.8H), 5.76 (s, 0.2H), 4.63 (m, 0.7H), 4.37 (m, 0.3H), 3.80 (d, *J* = 5.7 Hz, 6H), 3.66 (s, 3H), 3.23-3.28 (m, 1H), 3.12-3.13 (m, 2H), 1.43 (m, 2H), 1.23 (s, 30H), 0.85 (t, *J* = 6 Hz, 3H); MS (ESI) *m/z* 551.60 (M+1).

(2*RS*, 4*R*)-2-(4-Acetylamino-phenyl)-thiazolidine-4-carboxylic acid octadecylamide

Hydrochloride (18.HCl). ¹H NMR (DMSO-*d*₆) δ 10.18 (s, 1H), 8.61 (m, 1H), 7.54-7.64 (m, 4H), 5.82 (s, 0.7H), 5.77 (s, 0.3H), 4.60 (m, 0.8H), 4.42 (m, 0.2H), 3.56-3.64 (m, 1H), 3.12-

3.26 (m, 3H), 2.05 (s, 3H), 1.43 (m, 2H), 1.23 (s, 30H), 0.84 (t, $J = 6$ Hz, 3H); MS (ESI) m/z 518.70 ($M+1$).

(2*RS*, 4*R*)-2-(4-Fluoro-phenyl)-thiazolidine-4-carboxylic acid octadecylamide (19). ^1H NMR (CDCl_3) δ 7.46-7.54 (m, 2H), 7.13-7.20 (m, 1H), 7.01-7.08 (m, 2H), 5.60 (s, 0.3H), 5.34 (s, 0.7H), 4.76 (m, 0.3H), 4.34 (m, 0.7H), 3.69 (dd, $J = 11.1, 6.9$ Hz, 1H), 3.21-3.52 (m, 3H), 1.49 (m, 2H), 1.26 (s, 30H), 0.89 (t, $J = 6.3$ Hz, 3H); MS (ESI) m/z 479.60 ($M+1$).

(2*RS*, 4*R*)-2-(4-Bromo-phenyl)-thiazolidine-4-carboxylic acid octadecylamide (20). ^1H NMR (CDCl_3) δ 7.48-7.62 (m, 2H), 7.36-7.42 (m, 2H), 7.14 (m, 0.7H), 6.40 (m, 0.3), 5.57 (d, $J = 10.2$ Hz, 0.3H), 5.33 (d, $J = 11.1$ Hz, 0.7H), 4.32 (m, 0.7H), 3.94 (m, 0.3H), 3.70 (dd, $J = 11.1, 4.2$ Hz, 1H), 3.20-3.44 (m, 3H), 1.49 (m, 2H), 1.27 (s, 30H), 0.89 (t, $J = 6.3$ Hz, 3H); MS (ESI) m/z 539.70 (M^+).

(2*RS*, 4*R*)-2-(4-Nitro-phenyl)-thiazolidine-4-carboxylic acid octadecylamide (21). ^1H NMR (CDCl_3) δ 8.24 (d, $J = 8.7$ Hz, 2H), 7.67 (d, $J = 8.7$ Hz, 2H), 6.92 (m, 1H), 5.54 (s, 0.5H), 5.50 (s, 0.5H), 4.24-4.31 (m, 1H), 3.67 (dd, $J = 10.8, 4.8$ Hz, 1H), 3.27-3.44 (m, 3H), 1.55 (m, 2H), 1.26 (s, 30H), 0.89 (t, $J = 6.3$ Hz, 3H); MS (ESI) m/z 506.60 ($M+1$).

(2*RS*, 4*R*)-2-(4-Cyano-phenyl)-thiazolidine-4-carboxylic acid octadecylamide (22). ^1H NMR (CDCl_3) δ 7.60-7.70 (m, 4H), 6.94 (m, 0.6H), 6.37 (m, 0.4), 5.64 (s, 0.4H), 5.46 (s, 0.6H), 4.27 (m, 0.6H), 3.96 (m, 0.4H), 3.65-3.70 (m, 1H), 3.20-3.45 (m, 3H), 1.54 (m, 2H), 1.26 (s, 30H), 0.89 (t, $J = 6.3$ Hz, 3H); MS (ESI) m/z 508.50 ($M+\text{Na}$).

(2*RS*, 4*R*)-2-(3,5-Difluoro-phenyl)-thiazolidine-4-carboxylic acid octadecylamide (23). ^1H NMR (CDCl_3) δ 7.04-7.08 (m, 2H), 6.97 (m, 1H), 6.79 (m, 1H), 5.40 (s, 0.5H), 5.36 (s, 0.5H), 4.23-4.30 (m, 1H), 3.66 (dd, $J = 11.1, 4.5$ Hz, 1H), 3.26-3.42 (m, 3H), 1.33 (m, 2H), 1.26 (s, 30H), 0.89 (t, $J = 6.3$ Hz, 3H); MS (ESI) m/z 497.50 ($M+1$).

(2*RS*, 4*R*)-2-(2,6-Dichloro-phenyl)-thiazolidine-4-carboxylic acid octadecylamide (24). ¹H NMR (CDCl₃) δ 7.34-7.38 (m, 2H), 7.15-7.28 (m, 2H), 6.29 (s, 0.5H), 6.25 (s, 0.5H), 4.25 (t, *J* = 5.7 Hz, 1H), 3.94 (dd, *J* = 10.5, 1.8 Hz, 1H), 3.26-3.52 (m, 3H), 1.52 (m, 2H), 1.26 (s, 30H), 0.89 (t, *J* = 6 Hz, 3H); MS (ESI) *m/z* 529.70 (M⁺).

(2*RS*, 4*R*)-2-(3-Bromo-4-fluoro-phenyl)-thiazolidine-4-carboxylic acid octadecylamide (25). ¹H NMR (CDCl₃) δ 7.71 (m, 1H), 7.42 (m, 1H), 7.06-7.16 (m, 2H), 5.56 (d, *J* = 9.3 Hz, 0.2H), 5.34 (d, *J* = 10.2 Hz, 0.8H), 4.29 (d, *J* = 4.5 Hz, 0.8H), 3.94 (m, 0.2H), 3.69 (dd, *J* = 11.1, 4.2 Hz, 1H), 3.21-3.41 (m, 3H), 1.52 (m, 2H), 1.26 (s, 30H), 0.89 (t, *J* = 6.3 Hz, 3H); MS (ESI) *m/z* 558.70 (M+1).

(2*RS*, 4*R*)-2-*p*-Tolyl-thiazolidine-4-carboxylic acid octadecylamide (26). ¹H NMR (CDCl₃) δ 7.34-7.43 (m, 2H), 7.14-7.21 (m, 3H), 5.59 (s, 0.2H), 5.32 (s, 0.8H), 4.76 (m, 0.2H), 4.35 (m, 0.8H), 3.70 (dd, *J* = 11.1, 3.9 Hz, 1H), 3.21-3.43 (m, 3H), 2.36 (d, *J* = 2.7 Hz, 3H), 1.51 (m, 2H), 1.27 (s, 30H), 0.89 (t, *J* = 6.3 Hz, 3H); MS (ESI) *m/z* 475.60 (M+1).

(2*RS*, 4*R*)-2-Biphenyl-4-yl-thiazolidine-4-carboxylic acid octadecylamide Hydrochloride (27.HCl). ¹H NMR (DMSO-*d*₆) δ 8.59 (m, 1H), 7.66-7.73 (m, 5H), 7.37-7.51 (m, 4H), 5.92 (s, 0.7H), 5.87 (s, 0.3H), 4.62 (m, 0.7H), 4.41 (m, 0.3H), 3.53-3.64 (m, 1H), 3.26-3.32 (m, 1H), 3.13-3.17 (m, 2H), 1.44 (m, 2H), 1.22 (s, 30H), 0.84 (t, *J* = 6.3 Hz, 3H); MS (ESI) *m/z* 537.70 (M+1).

(2*RS*, 4*R*)-3-Acetyl-2-phenylthiazolidine-4-carboxylic acid octadecylamide (28). ¹H NMR (CDCl₃) δ 7.31-7.41 (m, 5H), 6.01 (s, 1H), 5.12 (s, 1H), 3.73 (m, 1H), 3.40 (m, 1H), 3.31 (m, 1H), 3.11-3.17 (m, 1H), 2.00 (s, 3H), 1.27-1.33 (m, 32H), 0.89 (t, *J* = 6.3 Hz, 3H); MS (ESI) *m/z* 502.60 (M⁺).

(2*RS*, 4*R*)-3-Methanesulfonyl-2-phenylthiazolidine-4-carboxylic acid octadecylamide (29).

¹H NMR (CDCl₃) δ 7.65-7.68 (m, 2H), 7.32-7.36 (m, 3H), 6.20 (s, 1H), 4.63 (dd, *J* = 9, 6 Hz, 1H), 3.67 (dd, *J* = 12, 6 Hz, 1H), 3.47 (dd, *J* = 12.3, 8.1 Hz, 1H), 3.04-3.13 (m, 2H), 3.02 (s, 3H), 1.27 (m, 32H), 0.89 (t, *J* = 6.3 Hz, 3H); MS (ESI) *m/z* 538.70 (M⁺).

2-Phenylthiazolidine-4-carboxylic acid methyl ester (31). To a solution of DL-cysteine (3g, 24.76 mmol) in MeOH (50 mL) at 0°C, SOCl₂ (2.76 mL, 37.14 mmol) was slowly added and warmed to room temperature then refluxed for 3 h. The reaction mixture was concentrated in vacuo to yield a residue. This residue was taken in to aqueous EtOH (1:1, 30 mL), NaHCO₃ (2.28 g, 27.23 mmol) was added, after 10 min benzaldehyde (2.5 mL, 24.76 mmol) was added and stirring continued for 3 h. CHCl₃ (200 mL) was added to the reaction mixture and washed with water, brine, dried (Na₂SO₄) and solvent was removed in vacuo. The crude product was purified by column chromatography to afford **31** (4.7 g, 85%). ¹H NMR (CDCl₃) δ 7.51-7.62 (m, 2H), 7.32-7.42 (m, 3H), 5.84 (s, 0.4H), 5.58 (s, 0.6H), 4.24 (t, *J* = 6.3 Hz, 0.4H), 4.01 (t, *J* = 7.5 Hz, 0.6H), 3.83 (s, 3H), 3.39-3.55 (m, 1H), 3.10-3.26 (m, 1H); MS (ESI) *m/z* 224 (M+1).

2-Phenylthiazole-4-carboxylic acid methyl ester (32). Compound **32** was synthesized following a reported procedure.¹⁴ Yield (0.33 g, 68%). ¹H NMR (CDCl₃) δ 8.20 (s, 1H), 8.0-8.04 (m, 2H), 7.45-7.50 (m, 3H), 4.0 (s, 3H); MS (ESI) *m/z* 220 (M+1).

2-Phenylthiazole-4-carboxylic acid octadecylamide (34). To a solution of **32** (0.5 g, 2.28 mmol) in MeOH (10 mL) at 0°C, 1N NaOH (5 mL) was added and stirred for 2 h. To the reaction mixture EtOAc (30 mL) was added and acidified with 1N HCl. Extracted with EtOAc (3 X 50 mL), combined extracts were washed with water, brine, dried (Na₂SO₄) and solvent was removed under vacuo to give crude acid **33**, which was converted to **34** (0.30 g, 68%), following the general procedure used as in the case of synthesis of **3-27**. ¹H NMR (CDCl₃) δ

8.10 (s, 1H), 7.96-7.93 (m, 2H), 7.46-7.50 (m, 3H), 3.49 (dd, $J = 13.5, 6.9$ Hz, 2H), 1.69 (m, 2H), 1.27 (m, 30H), 0.89 (t, $J = 6.3$ Hz, 3H); MS (ESI) m/z 457.60 ($M+1$).

Cell Culture. DU-145, PC-3, and LNCaP human prostate cancer cells, and RH7777 rat hepatoma cells were obtained from American Type Culture Collection (Manassas, VA). Dr. Mitchell Steiner at University of Tennessee Health Science Center kindly provided PPC-1 and TSU-Pr1 cells. Prostate cancer cells and RH7777 cells were maintained in RPMI 1640 medium and DMEM (Mediatech, Inc., Herndon, VA), respectively, supplemented with 10% fetal bovine serum (Gibco, Grand Island, NY) in 5% CO₂/95% air humidified atmosphere at 37 °C.

RT-PCR Analysis of LPA Receptor Expression. Total RNA was extracted using TRIzol[®] reagent (Invitrogen Corp., Carlsbad, CA) according to the manufacturer's instruction. 0.5 µg (LPA₁) or 1 µg (LPA₂ and LPA₃) of total RNA was used to perform RT-PCR using SuperScript[™] One-Step RT-PCR with Platinum[®] *Taq* (Invitrogen Corp., Carlsbad, CA) with 0.2 µM of primers. The following primer pairs were used: LPA₁ forward 5'-GCTCCACACACGGATGAGCAACC-3', LPA₁ reverse 5'-GTGGTCATTGCTGTGAACTCCAGC-3'; LPA₂ forward 5'-CTGCTCAGCCGCTCCTATTTG-3', LPA₂ reverse 5'-AGGAGCACCCACAAGTCATCAG-3'; LPA₃ forward 5'-CCATAGCAACCTGACCAAAAAGAG-3', LPA₃ reverse 5'-TCCTTGTAGGAGTAGATGATGGGG-3'; β-actin forward 5'-GCTCGTCGTCGACAACGGCTC-3', β-actin reverse 5'-CAAACATGATCTGGGTCATCTTCTC-3'. PCR conditions were as follows: After 2 min denaturation step at 94 °C, samples were subjected to 34 to 40 cycles at 94 °C for 30

sec, 60 °C (LPA₁) or 58 °C (LPA₂ and LPA₃) for 30 sec, and 72 °C for 1 min, followed by an additional elongation step at 72 °C for 7 min. Primers were selected to span at least one intron of the genomic sequence to detect genomic DNA contamination. The PCR products were separated on 1.5% agarose gels, stained with ethidium bromide, and the band intensity was quantified using Quantity One Software (Bio-Rad Laboratories, Inc., Hercules, CA). Expression levels of each receptor subtype in different cell lines were expressed as ratios compared to β -actin mRNA level.

Cytotoxicity Assay. For in vitro cytotoxicity screening, 1000 to 5000 cells were plated into each well of 96-well plates depending on growth rate, and exposed to different concentrations of a test compound for 96 h in three to five replicates. All the compounds were dissolved in dimethyl sulfoxide at 5 to 20 mM, and diluted to desired concentrations in complete culture medium. Cell numbers at the end of the drug treatment were measured by the SRB assay. Briefly, the cells were fixed with 10% of trichloroacetic acid, stained with 0.4% SRB, and the absorbances at 540 nm was measured using a plate reader (DYNEX Technologies, Chantilly, VA). Percentages of cell survival versus drug concentrations were plotted and the IC₅₀ (concentration that inhibited cell growth by 50% of untreated control) values were obtained by nonlinear regression analysis using WinNonlin (Pharsight Corporation, Mountain View, CA). 5-fluorouracil was used as a positive control to compare potencies of the new compounds.

Apoptosis. A sandwich ELISA (Roche, Mannheim, Germany) utilizing monoclonal antibodies specific for DNA and histones was used to quantify degree of apoptosis induced by the analogs after 72 h exposure. This assay measures DNA-histone complexes (mono- and oligonucleosomes) released into cytoplasm from the nucleus during apoptosis.

RH7777 cells were employed because of nonspecific cytotoxicity of compound **4** in receptor-negative cells as well as receptor-positive prostate cancer cells.

Acknowledgements

This research was supported by a grant from the Department of Defense (DAMD17-01-1-083). Pharsight Corporation generously provided WinNonlin software through an Academic License.

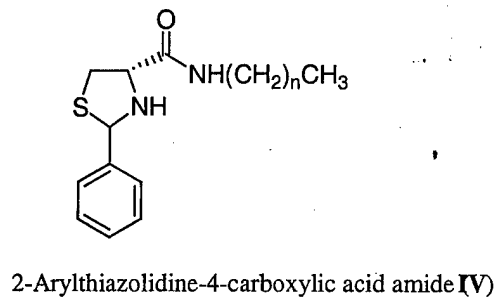
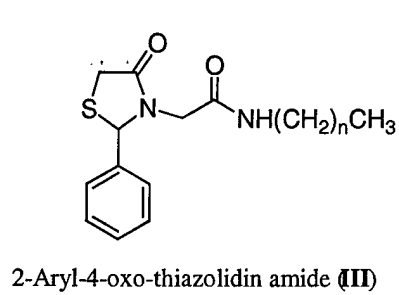
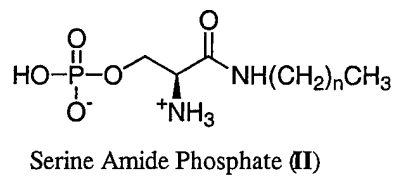
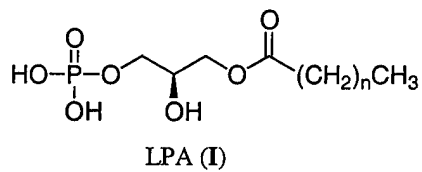
Supporting Information Available: General procedure for the preparation of compounds **2a-2v** along with spectral data is available free of charge via the Internet at <http://pubs.acs.org>.

References

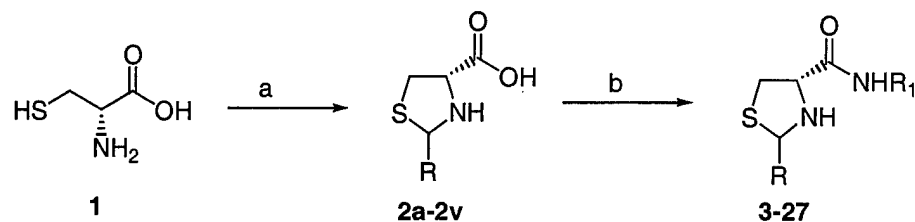
1. Raj, G. V.; Barki-Harrington, L.; Kue, P. F.; Daaka, Y. Guanosine phosphate binding protein coupled receptors in prostate cancer: a review. *J. Urol.* **2002**, *167*, 1458-1463.
2. Kue, P.; Daaka, Y. Essential role for G proteins in prostate cancer cell growth and signaling. *J. Urol.* **2000**, *164*, 2162-2167.
3. Guo, C.; Luttrell, L. M.; Price, D. T. Mitogenic signaling in androgen sensitive and insensitive prostate cancer cell lines. *J. Urol.* **2000**, *163*, 1027-1032.
4. Barki-Harrington, L.; Daaka, Y. Bradykinin induced mitogenesis of androgen independent prostate cancer cells. *J. Urol.* **2001**, *165*, 2121-2125.
5. Bex, A.; Lummen, G.; Rembrink, K.; Otto, T.; Metz, K.; Rubben, H. Influence of pertussis toxine on local progression and metastasis after orthotopic implantation of the human prostate cancer cell line PC3 in nude mice. *Prostate Cancer Prostatic Dis.* **1999**, *2*, 36-40.
6. Qi, C.; Park, J. H.; Gibbs, T. C.; Shirley, D. W.; Bradshaw, C. D.; Ella, K. M.; Meier, K. E. Lysophosphatidic acid stimulates phospholipase D activity and cell proliferation in PC-3 human prostate cancer cells. *J. Cell. Physiol.* **1998**, *174*, 261-272.
7. Daaka, Y. Mitogenic action of LPA in prostate. *Biochim Biophys Acta.* **2002**, *1582*, 265-269.
8. Vivanco, I.; Sawyers, C. L. The phosphatidylinositol 3-Kinase AKT pathway in human cancer. *Nat Rev Cancer.* **2002**, *2*, 489-501.

9. Gududuru, V.; Hurh, E.; Durgam, G. G.; Hong, S. S.; Sardar, V. M.; Xu, H.; Dalton, J. T.; Miller, D. D. Synthesis and biological evaluation of novel cytotoxic phospholipids for prostate cancer. *Bioorg. Med. Chem. Lett.* **2004**, *14*, 4919-4923.
10. Gududuru, V.; Hurh, E.; Dalton, J. T.; Miller, D. D. Synthesis and Antiproliferative Activity of 2-Aryl-4-oxo-thiazolidin-3-yl-amides for Prostate Cancer. *Bioorg. Med. Chem. Lett.* **2004**, *14*, 5289-5293.
11. Seki, M.; Mori, Y.; Hatsuda, M.; Yamada, S. A Novel Synthesis of (+)-Biotin from L-Cysteine. *J. Org. Chem.* **2002**, *67*, 5527-5536.
12. Svetlov, S.; Sautin, I. Y.; Crawford, J. M. EDG receptors and hepatic pathophysiology of LPA and S1P: EDG-ology of liver injury. *Biochimica et biophysica acta.* **2002**, *1582*, 251-256.
13. Huang, H.; Cheville, J. C.; Pan, Y.; Roche, P. C.; Schmidt, L. J.; Tindall, D. J. PTEN induces chemosensitivity in PTEN-mutated prostate cancer cells by suppression of Bcl-2 expression. *J. Biol. Chem.* **2001**, *276*, 38830-38836.
14. Badr, M. Z.; Aly, M. M.; Fahmy, A. M.; Mansour, E. Y. Synthesis of Oxazolidines, Thiazolidines, and 5,6,7,8-Tetrahydro-1*H*, 3*H*-pyrrolo[1,2-*c*]oxazole (or thiazole)-1,3diones from β -Hydroxy- or β -Mercapto- α -amino Acid Esters. *Bull. Chem. Soc. Jpn.* **1981**, *54*, 1844-1847.

Figure 1



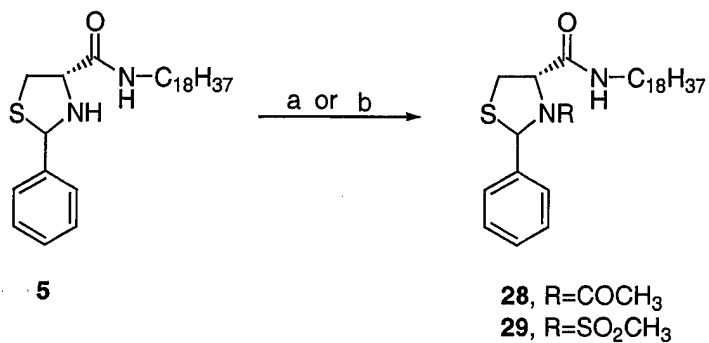
Scheme 1^a



Compd	R
2a	phenyl
2b	n-dodecyl
2c	cyclohexyl
2d	benzyl
2e	3-indolyl
2f	3-pyridinyl
2g	3-furanyl
2h	4-dimethyl amino phenyl
2i	3-hydroxyphenyl
2j	4-methoxyphenyl
2k	3,4-dimethoxyphenyl
2l	3,4,5-trimethoxyphenyl
2m	4-acetylamino phenyl
2n	4-fluorophenyl
2o	4-bromophenyl
2p	4-nitrophenyl
2q	4-cyanophenyl
2r	3,5-difluorophenyl
2s	2,6-dichlorophenyl
2t	3-bromo-4-fluorophenyl
2u	4-methylphenyl
2v	biphenyl

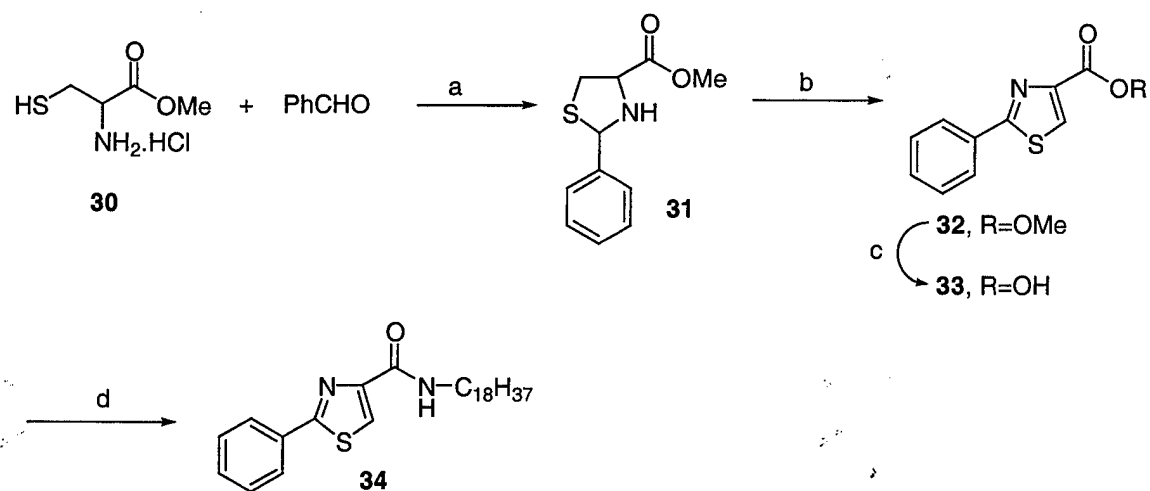
^aReagents and conditions: (a) RCHO, EtOH; (b) CH₃(CH₂)_nNH₂, EDC, HOBT, CH₂Cl₂

Scheme 2^a



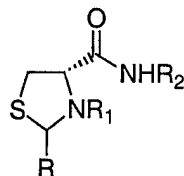
^aReagents and conditions: (a) Ac_2O , Pyridine; (b) $\text{CH}_3\text{SO}_2\text{Cl}$, Pyridine

Scheme 3^a



^aReagents and conditions: (a) NaHCO_3 , EtOH , H_2O ; (b) NBS , CCl_4 ; (c) NaOH , MeOH ; (d) $\text{C}_{18}\text{H}_{37}\text{NH}_2$, EDC , HOBt , CH_2Cl_2

Table 1. Structures and Physical Data of Synthesized Compounds



compd	R	R ₁	R ₂	mp (°C)	yield (%)	formula	anal.
3.HCl	phenyl	H	C ₇ H ₁₅	ND	80	C ₁₇ H ₂₇ ClN ₂ OS	C, H, N
4.HCl	phenyl	H	C ₁₄ H ₂₉	95	83	C ₂₄ H ₄₁ ClN ₂ OS	C, H, N
5.HCl	phenyl	H	C ₁₈ H ₃₇	93	70	C ₂₈ H ₄₉ ClN ₂ OS	C, H, N
6.HCl	phenyl	H	C ₁₉ H ₃₉	85	78	C ₂₉ H ₅₁ ClN ₂ OS	C, H, N
7	n-dodecyl	H	C ₁₈ H ₃₇	86	69	C ₃₄ H ₆₈ N ₂ OS	C, H, N
8	cyclohexyl	H	C ₁₈ H ₃₇	60	75	C ₂₈ H ₅₄ N ₂ OS	C, H, N
9	benzyl	H	C ₁₈ H ₃₇	80	81	C ₂₉ H ₅₀ N ₂ OS	C, H, N
10	3-indolyl	H	C ₁₈ H ₃₇	125	65	C ₃₀ H ₄₉ N ₃ OS	C, H, N
11	3-pyridinyl	H	C ₁₈ H ₃₇	94	63	C ₂₇ H ₄₇ N ₃ OS	C, H, N
12.HCl	3-furanyl	H	C ₁₈ H ₃₇	99	60	C ₂₆ H ₄₇ ClN ₂ O ₂ S	C, H, N
13	4-dimethyl amino phenyl	H	C ₁₈ H ₃₇	75	75	C ₃₀ H ₅₃ N ₃ OS	C, H, N
14	3-hydroxyphenyl	H	C ₁₈ H ₃₇	50	69	C ₂₈ H ₄₈ N ₂ O ₂ S	C, H, N
15.HCl	4-methoxyphenyl	H	C ₁₈ H ₃₇	95	70	C ₂₉ H ₅₁ ClN ₂ O ₂ S	C, H, N
16.HCl	3,4- dimethoxyphenyl	H	C ₁₈ H ₃₇	103	83	C ₃₀ H ₅₃ ClN ₂ O ₃ S	C, H, N
17.HCl	3,4,5- trimethoxyphenyl	H	C ₁₈ H ₃₇	115	70	C ₃₁ H ₅₅ ClN ₂ O ₄ S	C, H, N
18.HCl	4-acetylamino phenyl	H	C ₁₈ H ₃₇	170	63	C ₃₀ H ₅₂ ClN ₃ O ₂ S	C, H, N
19	4-fluorophenyl	H	C ₁₈ H ₃₇	65	73	C ₂₈ H ₄₇ FN ₂ OS	C, H, N
20	4-bromophenyl	H	C ₁₈ H ₃₇	81	77	C ₂₈ H ₄₇ BrN ₂ OS	C, H, N
21	4-nitrophenyl	H	C ₁₈ H ₃₇	115	60	C ₂₈ H ₄₇ N ₃ O ₃ S	C, H, N
22	4-cyanophenyl	H	C ₁₈ H ₃₇	90	70	C ₂₉ H ₄₇ N ₃ OS	C, H, N
23	3,5- difluorophenyl	H	C ₁₈ H ₃₇	113	70	C ₂₈ H ₄₆ F ₂ N ₂ OS	C, H, N
24	2,6- dichlorophenyl	H	C ₁₈ H ₃₇	49	80	C ₂₈ H ₄₆ Cl ₂ N ₂ OS	C, H, N

25	3-bromo-4-fluorophenyl	H	C ₁₈ H ₃₇	100	78	C ₂₈ H ₄₆ BrFN ₂ OS	C, H, N
26	4-methylphenyl	H	C ₁₈ H ₃₇	120	73	C ₂₉ H ₅₀ N ₂ OS	C, H, N
27.HCl	biphenyl	H	C ₁₈ H ₃₇	130	70	C ₃₄ H ₅₃ ClN ₂ OS	C, H, N
28	phenyl	COCH ₃	C ₁₈ H ₃₇	90	95	C ₃₀ H ₅₀ N ₂ O ₂ S	C, H, N
29	phenyl	SO ₂ CH ₃	C ₁₈ H ₃₇	55	90	C ₂₉ H ₅₀ N ₂ O ₃ S ₂	C, H, N

Table 2. LPL Receptor mRNA Expression

LPL Receptor	Old name	Expression level relative to β -actin					
		RH7777	DU145	PC-3	LNCaP	PPC-1	TSU-Pr1
LPA ₁	EDG-2	UD ^a	2.16	2.53	UD	2.29	2.13
LPA ₂	EDG-4	UD	0.33	0.43	0.32	0.41	0.19
LPA ₃	EDG-7	UD	0.07	0.27	0.28	0.15	UD
Sum LPA ₁₋₃		0	2.56	3.23	0.60	2.85	2.32

^aUD: under detection limit

Table 3. Antiproliferative Effects of Compounds **3-18**

Compd	IC ₅₀ (μM)					
	RH7777 ^a	DU-145 ^b	PC-3 ^b	LNCaP ^b	PPC-1 ^b	TSU-Pr1 ^b
3.HCl	52.2	44.9	38.5	12.4	34.7	28.0
4.HCl	3.4	2.4	3.0	1.4	1.3	2.0
5.HCl	25.6	5.4	7.8	2.1	2.0	5.0
6.HCl	No activity	> 20	No activity	13.6	16.8	> 20
7	~20	8.9	15.0	11.9	13.0	10.7
8	> 20	> 20	> 20	12.8	9.3	> 20
9	> 20	15.3	16.4	4.4	4.0	11.2
10	> 20	8.9	11.5	2.1	1.3	4.4
11	10.5	7.5	9.2	3.6	2.9	7.8
12.HCl	10.4	6.6	8.1	1.7	1.1	4.2
13	> 20	5.3	6.0	1.6	1.1	3.0
14	31.0	5.7	6.7	1.7	1.2	4.0
15.HCl	>20	8.7	~20	2.1	1.5	ND
16.HCl	10.3	4.5	5.2	0.85	0.58	2.4
17.HCl	11.4	3.9	4.0	0.82	0.48	2.4
18.HCl	21.1	3.1	5.6	1.3	0.55	0.94
5-FU	ND	11.9	12.0	4.9	6.4	3.6

^aControl cell line. ^bProstate cancer cell lines.

Table 4. Antiproliferative Effects of Compounds **19-29** and **34**

Compd	IC ₅₀ (μM)					
	RH7777 ^a	DU-145 ^b	PC-3 ^b	LNCaP ^b	PPC-1 ^b	TSU-Pr1 ^b
19	17.4	5.7	6.8	1.9	2.1	5.4
20	> 20	13.8	17.3	5.1	3.7	18.3
21	~ 20	15.3	~ 20	8.4	15.3	15.9
22	>20	>20	>20	5.9	5.0	>20
23	>20	>20	>20	11.2	10.6	>20
24	> 20	> 20	> 20	13.1	17.1	~ 20
25	~ 20	11.3	13.5	3.0	4.7	14.0
26	> 20	10.5	12.8	1.9	1.9	8.0
27.HCl	>20	>20	>20	>20	>20	>20
28	>20	~20	~20	16.1	12.6	>20
29	>20	>20	>20	>20	>20	>20
34	>20	>20	>20	>20	>20	>20
5-FU	ND	11.9	12.0	4.9	6.4	3.6

^aControl cell line. ^bProstate cancer cell lines.

Table 5. Thiazolidine amides- Induced Apoptosis

Compd for 72 h		PC-3	LNCaP	RH7777
4	2 μ M	1.8	14.1	2.6
	5 μ M	18.7	75.4	3.2
	10 μ M	54.0	80.7	2.5
5	2 μ M	1.4	4.5	ND ^a
	5 μ M	2.3	45.2	
	10 μ M	3.4	37.1	
	20 μ M	12.7	26.1	

^aND: not determined

Supporting Information

Discovery of 2-Arylthiazolidine-4-carboxylic acid amides as a New Class of Cytotoxic Agents for Prostate Cancer

Veeresa Gududuru, Eunju Hurh, James T. Dalton, and Duane D. Miller *

Contents: General procedure for the preparation of compounds **2a-2v** and their ^1H NMR (300 MHz) and MS (ESI) characterization data.

General Procedure for the Preparation of 2a-2v. A mixture of L-cysteine (**1**, 0.5g, 4.12 mmol) and appropriate aldehyde (4.12 mmol) in ethanol (15 mL) was stirred at room temperature for 5 h, the solid separated was collected, washed with diethyl ether and dried to afford **2a-2v**.

(2RS, 4R)-2-Phenylthiazolidine-4-carboxylic acid (2a). Obtained as colorless crystals (0.82 g, 95%). ^1H NMR (DMSO- d_6) δ 7.24-7.53 (m, 5H), 5.67 (s, 0.6H), 5.50 (s, 0.4H), 4.22 (dd, J = 6.9, 4.5 Hz, 0.6H), 3.90 (dd, J = 8.7, 7.2 Hz, 0.4H), 3.27-3.40 (m, 1H), 3.04-3.16 (m, 1H); MS (ESI) m/z 208 (M-1).

(2RS, 4R)-2-Dodecylthiazolidine-4-carboxylic acid (2b). Obtained as colorless powder (0.87 g, 70%). ^1H NMR (DMSO- d_6) δ 4.53 (t, J = 6.9 Hz, 0.4H), 4.38 (t, J = 6.9 Hz, 0.6H), 4.03 (t, J = 6.9 Hz, 0.5H), 3.64-3.69 (m, 0.5H), 3.41-3.45 (m, 0.5H), 3.05-3.21 (m, 0.5H), 2.76-2.92 (m, 1H), 1.66-1.71 (m, 2H), 1.23 (brs, 20H), 0.85 (t, J = 6 Hz, 3H); MS (ESI) m/z 300 (M- 1).

(2RS, 4R)-2-Cyclohexylthiazolidine-4-carboxylic acid (2c). Colorless solid (0.88 g, 100%). ^1H NMR (DMSO- d_6) δ 4.34 (d, J = 8.4 Hz, 0.6H), 4.23 (d, J = 8.1 Hz, 0.4H), 4.0 (t, J = 5.7 Hz, 0.5H), 3.64-3.70 (m, 0.5H), 3.12-3.17 (m, 0.5H), 2.97-3.0 (m, 0.5H), 2.82-2.89 (m, 0.5H), 2.65

(t, $J = 9$ Hz, 0.5H), 1.95 (m, 1H), 1.55-1.66 (m, 4H), 0.89-1.21 (m, 6H); MS (ESI) m/z 214 (M- 1).

(2RS, 4R)-2-Benzylthiazolidine-4-carboxylic acid (2d). Colorless solid (0.73 g, 80%). ^1H NMR (DMSO- d_6) δ 7.17-7.29 (m, 5H), 4.81 (t, $J = 6.9$ Hz, 0.5H), 4.64 (t, $J = 7.2$ Hz, 0.5H), 4.12 (t, $J = 6.6$ Hz, 0.5H), 3.67-3.73 (m, 0.5H), 2.93-3.28 (m, 4H); MS (ESI) m/z 222 (M- 1).

(2RS, 4R)-2-(1H-Indol-3yl)-thiazolidine-4-carboxylic acid (2e). Yield (0.71 g, 70%). ^1H NMR (DMSO- d_6) δ 11.10 (m, 1H), 6.97-7.65 (m, 5H), 5.94 (s, 0.5H), 5.80 (s, 0.5H), 4.27-4.31 (m, 0.5H), 3.89 (t, $J = 7.8$ Hz, 0.5H), 2.78-3.47 (m, 2H); MS (ESI) m/z 247 (M- 1).

(2RS, 4R)-2-Pyridin-3-yl-thiazolidine-4-carboxylic acid (2f). Yield (0.32 g, 63%). ^1H NMR (DMSO- d_6) δ 8.68 (d, $J = 2.1$ Hz, 0.5H), 8.61 (d, $J = 2.1$ Hz, 0.5H), 8.52 (dd, $J = 4.8, 1.8$ Hz, 0.5H), 8.46 (dd, $J = 4.8, 1.5$ Hz, 0.5H), 7.95-7.99 (m, 0.5H), 7.81-7.85 (m, 0.5H), 7.34-7.42 (m, 1H), 5.74 (s, 0.5H), 5.55 (s, 0.5H), 4.18 (m, 0.5H), 3.91 (m, 0.5H), 3.29-3.40 (m, 1H), 3.0-3.15 (m, 0.5H); MS (ESI) m/z 209 (M- 1).

(2RS, 4R)-2-Furan-3-yl-thiazolidine-4-carboxylic acid (2g). Yield (0.64 g, 78%). ^1H NMR (DMSO- d_6) δ 7.77 (s, 1H), 7.55 (m, 1H), 6.57 (s, 0.5H), 6.51 (s, 0.5H), 5.59 (s, 0.5H), 5.43 (s, 0.5H), 4.16 (t, $J = 6.6$ Hz, 0.5H), 3.83 ($J = 8.4$ Hz, 0.5H), 3.23-3.35 (m, 1H), 2.96-3.15 (m, 1H); MS (ESI) m/z 198 (M- 1).

(2RS, 4R)-2-(4-Dimethylamino-phenyl)-thiazolidine-4-carboxylic acid (2h). Yield (1.04 g, 100%). ^1H NMR (DMSO- d_6) δ 7.24-7.31 (m, 2H), 6.68 (t, $J = 8.4$ Hz, 2H), 5.54 (s, 0.5H), 5.39 (s, 0.5H), 4.23-4.27 (m, 0.5H), 3.81 (t, $J = 8.4$ Hz, 0.5H), 3.26-3.46 (m, 1H), 2.93-3.15 (m, 1H), 2.88 (d, $J = 8.4$ Hz, 6H); MS (ESI) m/z 251 (M- 1).

(2RS, 4R)-2-(3-Hydroxy-phenyl)-thiazolidine-4-carboxylic acid (2i). Yield (0.65 g, 70%). ^1H NMR (DMSO- d_6) δ 7.08-7.18 (m, 1H), 6.82-6.91 (m, 2H), 6.63-6.74 (m, 1H), 5.59 (s,

0.5H), 5.41 (s, 0.5H), 4.16-4.20 (m, 0.5H), 3.83-3.89 (m, 0.5H), 3.24-3.39 (m, 1H), 3.0-3.17 (m, 1H); MS (ESI) m/z 224 (M- 1).

(2*RS*, 4*R*)-2-(4-Methoxy-phenyl)-thiazolidine-4-carboxylic acid (2j). Yield (0.98 g, 100%).

^1H NMR (DMSO- d_6) δ 7.42 (d, J = 8.7 Hz, 1H), 7.34 (d, J = 8.7 Hz, 1H), 6.93 (d, J = 3 Hz, 1H), 6.87 (d, J = 3 Hz, 1H), 5.60 (s, 0.5H), 5.44 (s, 0.5H), 4.21-4.24 (m, 0.5H), 3.81-3.87 (m, 0.5H), 3.75 (d, J = 4.2 Hz, 3H), 2.81-3.46 (m, 2H); MS (ESI) m/z 238 (M- 1).

(2*RS*, 4*R*)-2-(3,4-Dimethoxy-phenyl)-thiazolidine-4-carboxylic acid (2k). Yield (0.99 g,

90%). ^1H NMR (DMSO- d_6) δ 6.86-7.15 (m, 3H), 5.57 (s, 0.5H), 5.43 (s, 0.5H), 4.26-4.30 (m, 0.5H), 3.73-3.76 (m, 6H), 3.26-3.37 (m, 1H), 3.03-3.18 (m, 1H); MS (ESI) m/z 268 (M- 1).

(2*RS*, 4*R*)-2-(3,4,5-Trimethoxy-phenyl)-thiazolidine-4-carboxylic acid (2l). Yield (0.98 g,

80%). ^1H NMR (DMSO- d_6) δ 6.86 (s, 1H), 6.77 (s, 1H), 5.58 (s, 0.5H), 5.43 (s, 0.5H) 4.27-4.31 (m, 0.5H), 3.83-3.88 (m, 0.5H), 3.76 (d, J = 3.3 Hz, 6H) 3.64 (d, J = 3.3 Hz, 3H), 3.26-3.36 (m, 1H), 3.04-3.18 (m, 1H); MS (ESI) m/z 298 (M- 1).

(2*RS*, 4*R*)-2-(4-Acetylamino-phenyl)-thiazolidine-4-carboxylic acid (2m). Yield (1.09 g,

100%). ^1H NMR (DMSO- d_6) δ 9.97 (d, J = 15 Hz, 1H), 7.50-7.57 (m, 2H), 7.42 (d, J = 8.7 Hz, 1H), 7.34 (d, J = 8.4 Hz, 1H), 5.60 (s, 0.5H), 5.44 (s, 0.5H), 4.23-4.27 (m, 0.5H), 3.81 (m, 0.5H), 3.25-3.46 (m, 1H), 3.05-3.16 (m, 1H), 2.03 (d, J = 2.4 Hz, 3H); MS (ESI) m/z 265 (M- 1).

(2*RS*, 4*R*)-2-(4-Fluoro-phenyl)-thiazolidine-4-carboxylic acid (2n). Yield (0.45 g,

81%). ^1H NMR (DMSO- d_6) δ 7.55-7.60 (m, 1H), 7.46-7.50 (m, 1H), 7.11-7.23 (m, 2H), 5.67 (s, 0.5H), 5.50 (s, 0.5H), 4.19-4.23 (m, 0.5H), 3.86-3.91 (m, 0.5H), 3.27-3.39 (m, 1H), 3.05-3.16 (m, 1H); MS (ESI) m/z 226 (M-1).

(2*RS*, 4*R*)-2-(4-Bromo-phenyl)-thiazolidine-4-carboxylic acid (2o). Yield (0.66 g, 93%). ¹H NMR (DMSO-*d*₆) δ 7.47-7.58 (m, 3H), 7.38 (d, *J* = 8.4 Hz, 1H), 5.67 (s, 0.5H), 5.49 (s, 0.5H), 4.14-4.18 (m, 0.6H), 3.86-3.91 (m, 0.4H), 3.26-3.38 (m, 1H), 3.04-3.13 (m, 1H); MS (ESI) *m/z* 287 (*M*- 1).

(2*RS*, 4*R*)-2-(4-Nitro-phenyl)-thiazolidine-4-carboxylic acid (2p). Yield (0.40 g, 65%). ¹H NMR (DMSO-*d*₆) δ 8.20 (dd, *J* = 12, 8.7 Hz, 2H), 7.80 (d, *J* = 8.7 Hz, 1H), 7.67 (d, *J* = 8.7 Hz, 1H), 5.94 (s, 0.7H), 5.88 (s, 0.3H), 3.91-4.11 (m, 1H), 3.03-3.12 (m, 1H), 2.77-2.93 (m, 1H); MS (ESI) *m/z* 253 (*M*- 1).

(2*RS*, 4*R*)-2-(4-Cyano-phenyl)-thiazolidine-4-carboxylic acid (2q). Yield (0.40 g, 70%). ¹H NMR (DMSO-*d*₆) δ 7.68-7.85 (m, 2H), 7.60 (d, *J* = 8.1 Hz, 2H), 5.80 (s, 0.7H), 5.59 (s, 0.3H), 4.11 (t, *J* = 6 Hz, 0.8H), 3.90-3.96 (m, 0.2H), 3.27-3.38 (m, 1H), 3.04-3.11 (m, 1H); MS (ESI) *m/z* 233 (*M*- 1).

(2*RS*, 4*R*)-2-(3,5-Difluoro-phenyl)-thiazolidine-4-carboxylic acid (2r). Yield (0.46 g, 77%). ¹H NMR (DMSO-*d*₆) δ 7.30 (d, *J* = 6.6 Hz, 2H), 7.08-7.17 (m, 1H), 5.53 (s, 1H), 3.89-3.94 (m, 1H), 3.27-3.35 (m, 1H), 3.12 (t, *J* = 18 Hz, 1H); MS (ESI) *m/z* 244 (*M*- 1).

(2*RS*, 4*R*)-2-(2,6-Dichloro-phenyl)-thiazolidine-4-carboxylic acid (2s). Yield (0.47 g, 69%). ¹H NMR (DMSO-*d*₆) δ 7.55 (d, *J* = 0.9 Hz, 1H), 7.53 (s, 1H), 7.33-7.47 (m, 1H), 6.25 (s, 1H), 3.89 (dd, *J* = 9.9, 6.6 Hz, 1H), 3.47 (dd, *J* = 9.9, 6.6 Hz, 1H), 2.99 (t, *J* = 10.2 Hz, 1H); MS (ESI) *m/z* 277 (*M*- 1).

(2*RS*, 4*R*)-2-(3-Bromo-4-fluoro-phenyl)-thiazolidine-4-carboxylic acid (2t). Yield (0.5 g, 66%). ¹H NMR (DMSO-*d*₆) δ 7.93 (dd, *J* = 6.9, 2.1 Hz, 0.3H), 7.77 (dd, *J* = 6.6, 1.8 Hz, 0.7H), 7.45-7.59 (m, 1H), 7.35 (m, 1H), 5.68 (s, 0.7H), 5.50 (s, 0.3H), 4.16 (q, *J* = 6.6 Hz, 0.7H), 3.88 (q, *J* = 9 Hz, 0.3H), 3.24-3.36 (m, 1H), 3.06-3.13 (m, 1H); MS (ESI) *m/z* 305 (*M*- 1).

(2*RS*, 4*R*)-2-*p*-Tolyl-thiazolidine-4-carboxylic acid (2u). Yield (0.49 g, 90%). ¹H NMR (DMSO-*d*₆) δ 7.39 (d, *J* = 8.1 Hz, 1H), 7.31 (d, *J* = 8.1 Hz, 1H), 7.12-7.19 (m, 2H), 5.61 (s, 0.6H), 5.46 (s, 0.4H), 4.23 (q, *J* = 6.9 Hz, 0.5H), 3.87 (q, *J* = 8.7 Hz, 0.5H), 3.25-3.39 (m, 1H), 3.03-3.16 (m, 1H); MS (ESI) *m/z* 222 (M- 1).

(2*RS*, 4*R*)-2-Biphenyl-4-yl-thiazolidine-4-carboxylic acid (2v). Yield (0.66 g, 95%). ¹H NMR (DMSO-*d*₆) δ 7.33-7.68 (m, 10H), 5.74 (s, 0.6H), 5.55 (s, 0.4H), 4.23 (t, *J* = 6.9 Hz, 0.6H), 3.91 (t, *J* = 8.4 Hz, 0.4H), 3.29-3.47 (m, 1H), 3.06-3.17 (m, 1H); MS (ESI) *m/z* 284 (M- 1).