



**UNIVERSITI PUTRA MALAYSIA**

**SEMISYNTHESIS OF ANDROGRAPHOLIDE DERIVATIVES AND  
EVALUATION OF THEIR ANTITUMOUR PROPERTIES**

**JADA SRINIVASA RAO**

**FPSK(P) 2004 8**



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**By**

**JADA SRINIVASA RAO**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfilment of the Requirements for the Degree  
of Doctor of Philosophy**

**October 2004**



Abstract of this thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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**Chairman: Associate Professor Nasaruddin bin Abdul Aziz, M.D. M.Med. Sc.**

**Faculty: Medicine and Health Sciences**

Previously, andrographolide, which is the major diterpenoid of *Andrographis paniculata*, was shown to have *in vivo* antitumour activity against human breast tumour xenografts. In this study, among the four compounds isolated from *A. paniculata*, andrographolide was the most potent compound with a mean IC<sub>50</sub> value of 8 µM in MCF-7 human breast cancer cells. Neoandrographolide showed a weak cytotoxic effect, whereas 14-deoxy-11,12-didehydroandrographolide and 14-deoxyandrographolide failed to exhibit growth inhibitory effect at the highest tested concentration of 100 µM. Owing to this, andrographolide was considered as the lead compound in the discovery of potent and selective antitumour agents.

Using andrographolide isolated from *A. paniculata* as one of the starting materials, 3,19-



benzylidene andrographolide and 3,19-alkylidene andrographolide derivatives were synthesised by coupling of the two -OH groups present at C-3 and C-19 of andrographolide with different benzaldehydes and alkyl aldehydes, respectively. In addition, new derivatives were also synthesised by acetylation, oxidation, Heck and esterolysis reactions. The structures of new derivatives of andrographolide derivatives were confirmed by spectral analysis ( $^1\text{H}/^{13}\text{C}$  NMR, MS, FT-IR, UV).

Forty seven compounds including andrographolide were tested for antitumour activities in MCF-7 and HCT-116 (colon) cancer cell lines. Using a 72 h MTT cell viability assay, parameters of dose-response effects,  $\text{GI}_{50}$ , TGI and  $\text{LC}_{50}$  were determined. The derivatives had submicromolar  $\text{GI}_{50}$  values, except for 3,19-(4-nitrobenzylidene)andrographolide (**SRJ58**), which showed the most potent activity with a  $\text{GI}_{50}$  value of 0.7  $\mu\text{M}$  in MCF-7 cells. Only (Z)-2-[1-benzylamino-2-(5,5,6,8a-tetramethyl-2-methylene-decahydro-naphthalen-1-yl)-ethyl]-4-hydroxy-but-2-enoic acid benzylamide] (**SRJ18**), displayed a pronounced selectivity (approximately 8-fold) towards HCT-116 cells at the  $\text{GI}_{50}$  value compared with MCF-7 cells.

Out of the five compounds (3,19-isopropylideneandrographolide (**SRJ01**), 14-acetylandrographolide (**SRJ03**), 3,19-(2-bromobenzylidene)-14-deoxy-11,12-didehydro andrographolide (**SRJ05**), 3,19-(2-bromobenzylidene)andrographolide (**SRJ09**) and 3,19-(3,4-dimethoxybenzylidene)andrographolide (**SRJ13**)) tested against the 60 National Cancer Institute (NCI) of USA human cancer cell lines, only **SRJ09** showed some form of selectivity towards cancers of the colon, central nervous system, renal and melanoma. The mechanism(s) of actions of the compounds were also studied by



determining their effect in inducing cell cycle arrest and apoptosis. Andrographolide, **SRJ01** and **SRJ03** induced G<sub>1</sub> and G<sub>2</sub>/M arrest in MCF-7 cells, whereas 3,19-(4-bromobenzylidene)andrographolide (**SRJ08**), **SRJ09**, 3,19-(3-bromobenzylidene)andrographolide (**SRJ10**), 3,19-(3-chloro-4-fluorobenzylidene)andrographolide (**SRJ23**) and 3,19-(2-fluorobenzylidene)andrographolide (**SRJ27**) induced only G<sub>1</sub>-phase arrest in MCF-7 cells. **SRJ09** down-regulated CDK4 (a G<sub>1</sub>-phase regulator) protein levels in MCF-7 cells, which explains the G<sub>1</sub>-phase arrest by the compound. NCI's COMPARE mechanistic analysis revealed that the compounds antitumour activities were not similar to that of standard anticancer drugs with known mechanisms of action. Projection of **SRJ03** in the Self-Organising Maps (SOMs) analyses of NCI suggested that this compound may be targeting cell cycle related phosphatases or kinases. However, andrographolide, **SRJ01**, **SRJ05**, **SRJ09** and **SRJ13** did not project in the known mechanism categories.

The mode(s) of cell death induced by **SRJ09** and **SRJ23**, identified by fluorescence microscopy and flow cytometry, was confirmed to be apoptosis in HCT-116 cells.

In conclusion, novel derivatives of andrographolide, especially **SRJ09**, **SRJ18** and **SRJ58** are potential lead molecules for future antitumour studies to discover prospective clinical candidates.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai syarat memenuhi keperluan untuk Ijazah Doktor Falsafah

## SEMISINTESIS TERBITAN ANDROGRAPHOLIDE DAN PENILAIAN CIRI-CIRI ANTITUMORNYA

Oleh

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Andrographolide merupakan diterpenoid utama tumbuhan *Andrographis paniculata* dan kajian terdahulu menunjukkan andrographolide mempunyai aktiviti anti-tumor secara *in vivo* terhadap xenograf tumor payudara manusia. Dalam kajian ini, andrographolide merupakan sebatian yang paling poten diantara empat sebatian daripada *A. paniculata*, dengan nilai min  $IC_{50}$  8  $\mu$ M dalam sel kanser payudara manusia MCF-7. Neoandrographolide mempamerkan kesan sitotoksik yang lemah, manakala 14-deoxy-11,12-didehydroandrographolide dan 14-deoxyandrographolide gagal menunjukkan kesan perencatan tumbesaran apabila diuji pada kepekatan tertinggi iaitu 100  $\mu$ M. Justeru itu, andrographolide telah dipilih sebagai sebatian asas dalam usaha menghasilkan agen antitumor yang poten dan selektif berasaskan struktur rangka andrographolide.

Dengan menggunakan andrographolide yang diasingkan daripada *A. paniculata* sebagai bahan asas, 3,19-benzilidene andrographolide dan 3,19-alkilidene andrographolide disintesis dengan mengkupelkan dua kumpulan –OH pada kedudukan C-3 dan C-19 andrographolide masing-masing dengan benzaldehid dan alkil aldehid. Selain itu, terbitan andrographolide juga disintesis melalui proses asetilasi, oksidasi, tindakbalas Heck dan esterolisis. Struktur bagi terbitan baru andrographolide disahkan dengan menggunakan analisis spektral ( $^1\text{H}/^{13}\text{C}$  NMR, MS, FT-IR, UV).

Kesemua sebatian termasuk andrographolide diuji untuk menentukan antitumor terhadap kultur kanser payudara, MCF-7 dan kanser kolon, HCT-116. Dengan menggunakan asai viabiliti sel MTT selama 72 jam, nilai  $\text{GI}_{50}$ , TGI dan  $\text{LC}_{50}$  ditentukan. Kesemua sebatian terbitan menunjukkan nilai  $\text{GI}_{50}$  submikromolar terhadap kedua-dua jenis sel terutamanya 3,19-(4-nitrobenzylidene)andrographolide (**SRJ58**), yang menunjukkan aktiviti paling poten dengan nilai  $\text{GI}_{50}$  pada  $0.7 \mu\text{M}$ . Antara sebatian-sebatian tersebut, 8-kali ganda (Z)-2-[1-Benzylamino-2-(5,5,6,8a-tetramethyl-2-methylene-decahydro-naphthalen-1-yl)-ethyl]-4-hydroxy-but-2-enoic acid benzylamide (**SRJ18**), menunjukkan selektiviti terhadap sel HCT-116 dengan katara pada nilai  $\text{GI}_{50}$  berbanding sel MCF-7.

Daripada lima sebatian (3,19-isopropylideneandrographolide (**SRJ01**), 14-acetylandrographolide (**SRJ03**), 3,19-(2-bromobenzylidene)-14-deoxy-11,12-didehydro andrographolide (**SRJ05**), 3,19-(2-bromobenzylidene)andrographolide (**SRJ09**) and 3,19-(3,4-dimethoxybenzylidene)andrographolide (**SRJ13**)) yang telah diuji ke atas 60 jenis sel kanser oleh National Cancer Institute (NCI), USA, hanya **SRJ09** menunjukkan



selektiviti terhadap kanser sistem saraf pusat dan melanoma.

Andrographolide, **SRJ01** dan **SRJ03** didapati mengaruh perencatan fasa  $G_1$  dan  $G_2/M$  pada sel MCF-7, manakala 3,19-(4-bromobenzylidene)andrographolide (**SRJ08**), **SRJ09**, 3,19-(3-bromobenzylidene) andrographolide (**SRJ10**), 3,19-(3-chloro-4-fluorobenzylidene)andrographolide (**SRJ23**) and 3,19-(2-fluorobenzylidene)-andrographolide (**SRJ27**) hanya merencatkan fasa  $G_1$  pada sel MCF-7. Kesan **SRJ09** terhadap (oerangsangan hitaran regulaton cyclin) yang bergantung terhadap kinase 4 (CDK4) telah ditentukan melalui analisis Western blot. **SRJ09** merencatkan tahap CDK4 pada sel MCF-7 setelah dirawat selama 72 jam. Analisis NCI COMPARE menunjukkan mekanisme aktiviti sebatian-sebatian ini, tidak sama seperti yang ada pada dadah antikanser yang diketahui. Projeksi **SRJ03** dalam analisis 'Self-Organising Maps' (SOMs) mencadangkan mekanisma tindakannya berkemungkinan bersasar ke atas enzim fosfatase atau kinase. Walau bagaimanapun, andrographolide, **SRJ01**, **SRJ05**, **SRJ09** dan **SRJ13** tidak dipamerkan dalam kategori mekanisma yang diketahui.

Mekanisma kematian sel yang diaruh oleh agen baru ini dikenalpasti melalui pemerhatian mikroskop pendaflor dan 'sitometri aliran'. Daripada kedua-dua kaedah ini, apoptosis dikenal pasti sebagai mekanisma utama kematian sel HCT-116 yang dirawat dengan **SRJ09** dan **SRJ23**.

Secara kesimpulan, sebahagian sebatian terbitan andrographolide, terutamanya **SRJ09**, **SRJ18** dan **SRJ58** mempunyai potensi sebagai komponen utama kajian antitumor untuk menemui calon klinikal yang bekesan di masa hadapan.



## ACKNOWLEDGEMENTS

Firstly, I would like to thank my supervisor Dr Johnson Stanslas and co-supervisors Prof Dr Nordin Hj. Lajis, Assoc Prof Dr Mohammad Said Saad and Assoc Prof Dr Ahmad Sazali for their support through out my research. Special thanks to Dr Stanslas for giving me the opportunity to carry out this project and also for providing the chance to work at the Cancer Research Laboratories (CRL), School of Pharmacy, University of Nottingham, United Kingdom.

I am most thankful to Professor Malcolm Stevens, for allowing me to work at CRL and for his support and encouragement during the course of my research at Nottingham.

I am indebted to Dr Andrew McCarroll for spending a huge amount of his time for discussing the synthetic chemistry aspects of this research work. I am grateful to Charlie Matthews for his help in teaching me tissue culture experiments. I am thankful to Dr Andrew Westwell, Dr Ian Hutchinson, Eiichiro and Cedric for their help and suggestions in performing synthesis work. Special thanks to Joe, Eng-Hui, Manish, Jenny and Naresh for their help during tissue culture work and for useful discussions. Heartful appreciation goes to technicians of CRL for their cooperation.

I would like to thank Koushik for his guidance throughout my research work at the Natural Products Laboratory, Institute of Bioscience, Universiti Putra Malaysia. I would also like to thank Sagineedu, Sitaram, Viknes, Velan and my lab mates, and technicians of the Faculty of Medicine and Health Sciences, and Institute Bioscience, UPM for their cooperation during my research period in Malaysia.



I am grateful to European Association for Cancer Research (EACR) and Cancer Research UK for their financial support during my stay at The University of Nottingham, UK. The Malaysian Ministry of Science, Technology and Innovation (MOSTI) is thanked for funding this project under the Intensification of Research in Priority Areas (IRPA) Programme (Grants: 06-02-04-0088 and 06-02-04-0603-EA001).

Finally, I would like to thank my family for their love, support and encouragement.



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**LIST OF ABBREVIATIONS**

<b>Ab-1</b>	Actin
<b>AO</b>	acridine orange
<b>AMPS</b>	ammonium persulfate
<b>AG</b>	andrographolide
<b>ATP</b>	adenosine triphosphate
<b>BSA</b>	bovine serum albumin
<b>CDK</b>	cyclin-dependent kinase
<b>CDKI</b>	cyclin-dependent kinase inhibitor
<b>CNS</b>	central nervous system
<b>COMPARE</b>	Computerised Pattern-recognition algorithm
<b>DAPI</b>	4,6-diamino-2-phenyl indole
<b>DMSO</b>	dimethyl sulfoxide
<b>DMF</b>	dimethyl formamide
<b>DNA</b>	deoxyribonucleic-acid
<b>ECL</b>	enzyme chemiluminescence
<b>EDTA</b>	ethylenediaminetetraacetic acid
<b>EGFR</b>	epidermal growth factor receptor
<b>EGTR</b>	ethylene glycol-bis ( $\beta$ -aminoethyl ether) <i>N, N, N', N'</i> -tetraacetic acid
<b>FACS</b>	fluorescence-activated cell sorter
<b>FCS</b>	foetal calf serum
<b>FITC</b>	fluorescein isothiocyanate
<b>GI<sub>50</sub></b>	50% growth inhibition



<b>H<sub>2</sub>O</b>	distilled water/sterile water
<b>HPLC</b>	high-pressure liquid chromatography
<b>HRP</b>	horseradish peroxidase
<b>IC<sub>50</sub></b>	50% inhibition concentration
<b>LC<sub>50</sub></b>	50% lethal concentration
<b>MTT</b>	3-[4,5-Dimethylthiazol-2-yl]-2,5-diphenyltetrazolium bromide
<b>NCI</b>	National Cancer Institute
<b>PBS</b>	phosphate-buffered saline
<b>PCC</b>	Pearson correlation coefficient
<b>PI</b>	propidium iodide
<b>PS</b>	phosphatidylserine
<b>PVDF</b>	polyvinylidene fluoride
<b>RNA</b>	ribonucleic acid
<b>RNase</b>	ribonuclease
<b>RPMI</b>	Roswell Park Memorial Institute
<b>SD</b>	standard deviation
<b>SDS</b>	sodium dodecyl sulphate
<b>SDS-PAGE</b>	sodium dodecyl sulphate polyacrylamide gel electrophoresis
<b>SOM</b>	self-organising maps
<b>TCM</b>	traditional Chinese medicine
<b>TEMED</b>	<i>N,N,N',N'</i> -tetramethylethylenediamine
<b>TGI</b>	total growth inhibition
<b>THF</b>	tetrahydrofuran
<b>TLC</b>	thin layer chromatography

## CHAPTER 1

### LITERATURE REVIEW

#### 1.1 Introduction

The use of plants as medicines goes back to early man. Certainly the great civilisations of the ancient Indians, Chinese, and North Africans provided written evidence of man's ingenuity in utilising plants for the treatment of a wide variety of diseases. In ancient Greece, scholars classified plants and gave descriptions of them thus aiding the identification process. It was not until the 19<sup>th</sup> century that man began to isolate the active principles of medicinal plants and one particular landmark was the discovery of quinine from *Cinchona* bark by the French scientists Caventou and Pelletier. Such discoveries led to an interest in plants from the New World and expeditions scoured the almost impenetrable jungles and forests in the quest for new medicines (reviewed by Phillipson, 2001). Despite major scientific and technological progress in combinatorial chemistry, drugs derived from natural products still make an enormous contribution to drug discovery today (reviewed by Phillipson, 2001).

Nature is an attractive source of new therapeutic candidate compounds and has a tremendous chemical diversity found in millions of species of plants, animals, marine organisms and microorganisms. The development of novel agents from natural sources presents obstacles that are not usually met when one deals with synthetic compounds. For instance, there may be difficulties in accessing the source of the samples, obtaining appropriate amounts of the sample, identification and isolation of the active compound in the sample, and problems in synthesising the necessary amounts of the compound of interest (Rocha *et al.*, 2001).



There are about 500,000 species of plants growing on the earth and it is estimated that at least 5000 different chemical compounds of secondary metabolites are present in a single species of plant (reviewed by Verpoorte, 1998). It is apparent that the secondary metabolites of plant origin constitute a tremendous resource for exploring useful drugs. In plants, the primary metabolites, including proteins, lipids, nucleic acids, enzymes, and coenzymes, etc., come from the metabolism of carbohydrates with the incorporation of nitrogen and mineral elements. By utilising primary metabolites and numerous infinite molecules, plants synthesise the secondary metabolites for the purpose of survival and well being. Taxonomically related plants generally produce chemically similar secondary metabolites and, therefore, may have similar pharmacological effects. Natural products exhibiting antitumour activity continue to be the subject of extensive research aimed at the development of drugs for the treatment of different human tumours.

In the early 1950s, a research program screening for antitumour drugs of plant origin was initiated mainly by the National Cancer Institute (NCI) in the USA. Large-scale screening procedures were made available, plant materials were produced, and crude extracts were put through preliminary screening. Basic pharmacological and toxicological studies in animals ensued, and finally, a number of promising compounds were selected for chemical studies, with the ultimate goal of finding the active antitumour drugs from plants. This program represented a combined effort mobilising many biomedical research organisations in the government and in medical, pharmaceutical, and chemical institutes and industries. The achievements during the past few decades have been very rewarding (reviewed by Cragg *et al.*, 1999).

