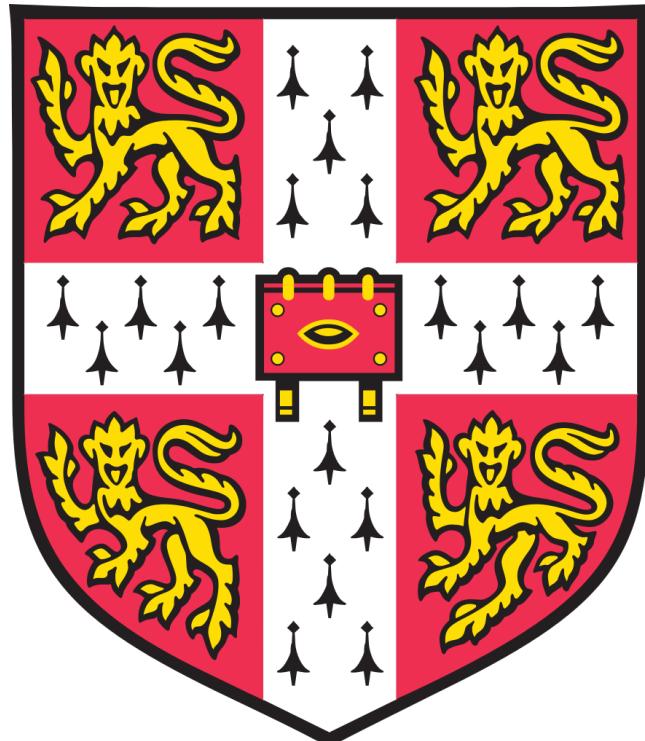


The synthesis and biological evaluation of a library of
autoinducer-antibiotic conjugates

Lois Overvoorde



Sidney Sussex College

University of Cambridge

June 2016

Supervised by Prof. David Spring

A dissertation submitted to the University of Cambridge in partial fulfilment of the
requirements for the Certificate of Postgraduate Studies

Contents

1 Nomenclature	8
2 Introduction	11
2.1 Antibiotic resistance	11
2.2 Quorum sensing	12
2.2.1 <i>Vibrio fischeri</i>	12
2.2.2 <i>Pseudomonas aeruginosa</i>	14
2.3 Siderophores	17
2.4 Sideromycins	19
2.5 Synthetic siderophore-antibiotic conjugates	20
2.6 Autoinducer-antibiotic conjugates	23
2.6.1 Synthesis of the conjugates	23
2.6.2 Autoinducers	23
2.6.3 Autoinducer efflux	23
2.6.4 Antibiotics	24
2.6.5 Antibiotic efflux	24
2.6.6 Conjugate efflux and antibiotic action	24
2.7 Autoinducer analogue-ciprofloxacin conjugates	25
3 Autoinducer-antibiotic conjugates	28
3.1 Introduction	28
3.1.1 Azido autoinducer derivatives	28
3.1.2 Alkynyl antibiotic derivatives	28
3.2 Azido autoinducer derivatives	29
3.2.1 Synthesis of 6-N ₃ -HHQ 46	29
3.2.2 Synthesis of 6-N ₃ -PQS 57	30
3.2.3 Synthesis of the azido C ₄ -HSL derivatives 63 , 66 and 69	32
3.3 Alkynyl antibiotic derivatives	33
3.3.1 Synthesis of the alkynyl ciprofloxacin derivative 76	33
3.3.2 Synthesis of the alkynyl trimethoprim derivative 79	34
3.4 Triazole-linked autoinducer-antibiotic conjugates	35
3.4.1 Optimisation of the click reaction	35
3.4.2 Synthesis of the autoinducer-ciprofloxacin and autoinducer-trimethoprim triazole conjugates	36
3.4.3 Synthesis of homoserine lactone-ciprofloxacin triazole conjugates with cleavable linkers	41
4 Autoinducer analogue-ciprofloxacin conjugates	42
4.1 Introduction	42
4.1.1 Head groups	42
4.1.2 Library construction	43
4.2 Homocysteine thiolactone derivatives	44
4.2.1 Synthesis of methyl ciprofloxacin 108	44
4.2.2 Synthesis of Br-C ₄ -HCTL 110	45
4.2.3 Synthesis of the HCTL-CipMe conjugate 111	45
4.2.4 Synthesis of the HCTL-Cip triazole conjugate 113	46
4.2.5 Synthesis of the cleavable HCTL-Cip triazole conjugate 114	47

4.3	2-Methoxybenzene derivatives	47
4.3.1	Synthesis of Br-C ₄ -2-methoxybenzene 116	47
4.3.2	Synthesis of the 2-methoxybenzene-CipMe conjugate 117	48
4.3.3	Synthesis of the 2-methoxybenzene-Cip triazole conjugate 119	48
4.4	3-Methoxybenzene derivatives	49
4.4.1	Synthesis of Br-C ₄ -3-methoxybenzene 121	49
4.4.2	Synthesis of the 3-methoxybenzene-CipMe conjugate 122	49
4.4.3	Synthesis of the 3-methoxybenzene-Cip triazole conjugate 124	50
4.5	Cyclopentanol derivatives	51
4.5.1	Synthesis of the 2-aminocyclopentan-1-ol head groups 129 and 130	51
4.5.2	Initial branching route	52
4.5.3	TBDMS protection route	54
4.5.3.1	Synthesis of TBDMS-protected (1 <i>S</i> ,2 <i>S</i>)-2-aminocyclopentan-1-ol 129	55
4.5.3.2	Synthesis of Br-C ₄ -cyclopentanol-TBDMS-(<i>SS</i>) 142	56
4.5.3.3	Synthesis of N ₃ -C ₄ -cyclopentanol-TBDMS-(<i>SS</i>) 144 by one-pot reaction	57
4.5.3.4	Synthesis of the (<i>SS</i>)-TBDMS-cyclopentanol-Cip triazole conjugate 148	57
4.5.4	Synthesis of the cyclopentanol-CipMe conjugates 135 and 136 by peptide coupling	58
4.5.5	Synthesis of the cyclopentanol-Cip triazole conjugates 138 and 139 via chloride intermediates	60
4.6	Cyclohexanol derivatives	63
4.6.1	Synthesis of the <i>trans</i> -2-aminocyclohexan-1-ol head group 157	63
4.6.2	Synthesis of the <i>trans</i> -cyclohexanol- and cyclohexanone-CipMe conjugates 158 and 159 .	64
4.6.3	Synthesis of the <i>trans</i> -cyclohexanol- and cyclohexanone-Cip triazole conjugates 162 and 163	64
5	Experimental	66
5.1	General	66
5.2	Methyl 3-oxodecanoate 41	67
5.3	Methyl (<i>E</i>)-3-((4-((<i>tert</i> -butoxycarbonyl)amino)phenyl)amino)dec-2-enoate 44	68
5.4	6-Amino-2-heptylquinolin-4-ol 45	68
5.5	6-Azido-2-heptylquinolin-4-ol 46	69
5.6	Heptyl magnesium bromide 48	70
5.7	2-Chloro- <i>N</i> -methoxy- <i>N</i> -methylacetamide 51	70
5.8	1-Chlorononan-2-one 52	70
5.9	2-Oxononyl 2-amino-5-nitrobenzoate 54	71
5.10	6-Nitro-2-heptyl-3-hydroxyquinolin-4(1 <i>H</i>)-one 55	72
5.11	6-Amino-2-heptyl-3-hydroxyquinolin-4(1 <i>H</i>)-one 56	72
5.12	6-Azido-2-heptyl-3-hydroxyquinolin-4(1 <i>H</i>)-one 57	73
5.13	(<i>S</i>)-3-Aminodihydrofuran-2(3 <i>H</i>)-one hydrobromide 60	74
5.14	(<i>S</i>)-2-Bromo- <i>N</i> -(2-oxotetrahydrofuran-3-yl)acetamide 62	74
5.15	(<i>S</i>)-2-Azido- <i>N</i> -(2-oxotetrahydrofuran-3-yl)acetamide 63	75
5.16	(<i>S</i>)-4-Bromo- <i>N</i> -(2-oxotetrahydrofuran-3-yl)butanamide 65	76
5.17	(<i>S</i>)-6-Bromo- <i>N</i> -(2-oxotetrahydrofuran-3-yl)hexanamide 68	76
5.18	(<i>S</i>)-6-Azido- <i>N</i> -(2-oxotetrahydrofuran-3-yl)hexanamide 69	77
5.19	Hex-5-ynal 71	78
5.20	<i>tert</i> -Butyl 4-(hex-5-yn-1-yl)piperazine-1-carboxylate 73	78
5.21	1-(Hex-5-yn-1-yl)piperazine 74	79

5.22 1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 76	80
5.23 4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenol 77	81
5.24 5-(4-(Hex-5-yn-1-yloxy)-3,5-dimethoxybenzyl)pyrimidine-2,4-diamine 79	81
5.25 Optimised general procedure for the click reaction	82
5.26 (<i>S</i>)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(2-oxo-2-((2-oxotetrahydrofuran-3-yl)amino)ethyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 80	82
5.27 (<i>S</i>)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(4-oxo-4-((2-oxotetrahydrofuran-3-yl)amino)butyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 85	84
5.28 (<i>S</i>)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(6-oxo-6-((2-oxotetrahydrofuran-3-yl)amino)hexyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 86	85
5.29 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(2-heptyl-4-oxo-1,4-dihydroquinolin-6-yl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 88	86
5.30 (<i>S</i>)-4-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1 <i>H</i> -1,2,3-triazol-1-yl)- <i>N</i> -(2-oxotetrahydrofuran-3-yl)butanamide 92	87
5.31 (<i>S</i>)-6-(4-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1 <i>H</i> -1,2,3-triazol-1-yl)- <i>N</i> -(2-oxotetrahydrofuran-3-yl)hexanamide 93	88
5.32 6-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1 <i>H</i> -1,2,3-triazol-1-yl)-2-heptylquinolin-4(1 <i>H</i>)-one 95	89
5.33 2-(6-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1 <i>H</i> -1,2,3-triazol-1-yl)hexyl-3-hydroxyquinolin-4(1 <i>H</i>)-one 97	90
5.34 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 108	91
5.35 4-Bromo- <i>N</i> -(2-oxotetrahydrothiophen-3-yl)butanamide 110	92
5.36 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 111	92
5.37 4-Azido- <i>N</i> -(2-oxotetrahydrothiophen-3-yl)butanamide 112	93
5.38 1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 113	94
5.39 1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(((4-(1-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butanoyl)oxy)methoxy)carbonyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 114	95
5.40 4-Bromo- <i>N</i> -(2-methoxyphenyl)butanamide 116	96
5.41 Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-((2-methoxyphenyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 117	97
5.42 4-Azido- <i>N</i> -(2-methoxyphenyl)butanamide 118	98
5.43 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((2-methoxyphenyl)amino)-4-oxobutyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 119	99
5.44 4-Bromo- <i>N</i> -(3-methoxyphenyl)butanamide 121	100
5.45 Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-((3-methoxyphenyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 122	101
5.46 4-Azido- <i>N</i> -(3-methoxyphenyl)butanamide 123	102
5.47 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((3-methoxyphenyl)amino)-4-oxobutyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 124	102
5.48 (1 <i>S</i> ,2 <i>S</i>)-2-(((<i>S</i>)-1-Phenylethyl)amino)cyclopentan-1-ol 127 and (1 <i>R</i> ,2 <i>R</i>)-2-(((<i>S</i>)-1-phenylethyl)amino)cyclopentan-1-ol 128	104
5.49 (1 <i>S</i> ,2 <i>S</i>)-2-Aminocyclopentan-1-ol 129	105
5.50 (1 <i>R</i> ,2 <i>R</i>)-2-Aminocyclopentan-1-ol 130	106

5.51 4-Azido- <i>N</i> -((1 <i>S</i> ,2 <i>S</i>)-2-hydroxycyclopentyl)butanamide 133	106
5.52 4-Azido- <i>N</i> -((1 <i>R</i> ,2 <i>R</i>)-2-hydroxycyclopentyl)butanamide 134	107
5.53 Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-((1 <i>S</i> ,2 <i>S</i>)-2-hydroxycyclopentyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 135	108
5.54 Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-((1 <i>R</i> ,2 <i>R</i>)-2-hydroxycyclopentyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 136	109
5.55 Methyl (<i>S</i>)-1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxocyclopentyl)amino)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 137	110
5.56 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((1 <i>S</i> ,2 <i>S</i>)-2-hydroxycyclopentyl)amino)-4-oxobutyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 138	111
5.57 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((1 <i>R</i> ,2 <i>R</i>)-2-hydroxycyclopentyl)amino)-4-oxobutyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 139	112
5.58 (1 <i>S</i> ,2 <i>S</i>)-2-((<i>tert</i> -Butyldimethylsilyl)oxy)cyclopentan-1-amine 140	113
5.59 4-Azido- <i>N</i> -((1 <i>S</i> ,2 <i>S</i>)-2-((<i>tert</i> -butyldimethylsilyl)oxy)cyclopentyl)butanamide 144	114
5.60 7-(4-(4-(1-(4-((1 <i>S</i> ,2 <i>S</i>)-2-((<i>tert</i> -butyldimethylsilyl)oxy)cyclopentyl)amino)-4-oxobutyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 148	115
5.61 Methyl 7-(4-(4-(<i>tert</i> -butoxy)-4-oxobutyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylate 151	116
5.62 4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid trifluoroacetate 152	117
5.63 4-Chloro- <i>N</i> -((1 <i>S</i> ,2 <i>S</i>)-2-hydroxycyclopentyl)butanamide 154	117
5.64 4-Chloro- <i>N</i> -((1 <i>R</i> ,2 <i>R</i>)-2-hydroxycyclopentyl)butanamide 155	118
5.65 (<i>trans</i>)-2-Aminocyclohexan-1-ol 157	119
5.66 Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-((<i>trans</i>)-2-hydroxycyclohexyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 158	120
5.67 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxocyclohexyl)amino)-butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 159	121
5.68 4-Chloro- <i>N</i> -((<i>trans</i>)-2-hydroxycyclohexyl)butanamide 160	122
5.69 4-Azido- <i>N</i> -((<i>trans</i>)-2-hydroxycyclohexyl)butanamide 161	122
5.70 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((<i>trans</i>)-2-hydroxycyclohexyl)amino)-4-oxobutyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 162	123
5.71 1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(4-oxo-4-((2-oxocyclohexyl)amino)butyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 163	124
6 NMR spectra	126
6.1 (<i>S</i>)-4-Bromo- <i>N</i> -(2-oxotetrahydrofuran-3-yl)butanamide 65	126
6.2 (<i>S</i>)-6-Bromo- <i>N</i> -(2-oxotetrahydrofuran-3-yl)hexanamide 68	127
6.3 (<i>S</i>)-6-Azido- <i>N</i> -(2-oxotetrahydrofuran-3-yl)hexanamide 69	128
6.4 <i>tert</i> -Butyl 4-(hex-5-yn-1-yl)piperazine-1-carboxylate 73	129
6.5 1-(Hex-5-yn-1-yl)piperazine 74	130
6.6 1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 76	131
6.7 5-(4-(Hex-5-yn-1-yloxy)-3,5-dimethoxybenzyl)pyrimidine-2,4-diamine 79	132
6.8 (<i>S</i>)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(2-oxo-2-((2-oxotetrahydrofuran-3-yl)amino)ethyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 80	133

6.9	(<i>S</i>)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-((1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 85	134
6.10	(<i>S</i>)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(6-((1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 86	135
6.11	1-Cyclopropyl-6-fluoro-7-(4-(4-((1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 88	136
6.12	(<i>S</i>)-4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxybutyl)-1 <i>H</i> -1,2,3-triazol-1-yl)- <i>N</i> -(2-oxotetrahydrofuran-3-yl)butanamide 92	137
6.13	(<i>S</i>)-6-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxybutyl)-1 <i>H</i> -1,2,3-triazol-1-yl)- <i>N</i> -(2-oxotetrahydrofuran-3-yl)hexanamide 93	138
6.14	6-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxybutyl)-1 <i>H</i> -1,2,3-triazol-1-yl)-2-heptylquinolin-4(<i>H</i>)-one 95	139
6.15	2-(6-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxybutyl)-1 <i>H</i> -1,2,3-triazol-1-yl)hexyl)-3-hydroxyquinolin-4(<i>H</i>)-one 97	140
6.16	4-Bromo- <i>N</i> -(2-oxotetrahydrothiophen-3-yl)butanamide 110	141
6.17	Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 111	142
6.18	4-Azido- <i>N</i> -(2-oxotetrahydrothiophen-3-yl)butanamide 112	143
6.19	1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)-1 <i>H</i> -1,2,3-triazol-4-yl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 113	144
6.20	1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(((4-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butanoyl)oxy)methoxy)carbonylpiperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 114	145
6.21	4-Bromo- <i>N</i> -(2-methoxyphenyl)butanamide 116	146
6.22	Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-((2-methoxyphenyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 117	147
6.23	1-Cyclopropyl-6-fluoro-7-(4-(4-((2-methoxyphenyl)amino)-4-oxobutyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 119	148
6.24	4-Bromo- <i>N</i> -(3-methoxyphenyl)butanamide 121	149
6.25	Methyl 1-cyclopropyl-6-fluoro-7-(4-(3-methoxyphenyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 122	150
6.26	4-Azido- <i>N</i> -(3-methoxyphenyl)butanamide 123	151
6.27	1-Cyclopropyl-6-fluoro-7-(4-(4-((3-methoxyphenyl)amino)-4-oxobutyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 124	152
6.28	4-Azido- <i>N</i> -((1 <i>S</i> ,2 <i>S</i>)-2-hydroxycyclopentyl)butanamide 133	153
6.29	4-Azido- <i>N</i> -((1 <i>R</i> ,2 <i>R</i>)-2-hydroxycyclopentyl)butanamide 134	154
6.30	Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-((1 <i>S</i> ,2 <i>S</i>)-2-hydroxycyclopentyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 135	155
6.31	Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-((1 <i>R</i> ,2 <i>R</i>)-2-hydroxycyclopentyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 136	156
6.32	1-Cyclopropyl-6-fluoro-7-(4-(4-((1 <i>S</i> ,2 <i>S</i>)-2-hydroxycyclopentyl)amino)-4-oxobutyl)-1 <i>H</i> -1,2,3-triazol-4-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 138	157
6.33	1-Cyclopropyl-6-fluoro-7-(4-(4-((1 <i>R</i> ,2 <i>R</i>)-2-hydroxycyclopentyl)amino)-4-oxobutyl)-1 <i>H</i> -1,2,3-triazol-4-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 139	158
6.34	4-Azido- <i>N</i> -((1 <i>S</i> ,2 <i>S</i>)-2-((<i>tert</i> -butyldimethylsilyloxy)cyclopentyl)butanamide 144	159

6.35 7-(4-(4-(1-(1 <i>S</i> ,2 <i>S</i>)-2-((<i>tert</i> -butyldimethylsilyl)oxy)cyclopentyl)amino)-4-oxobutyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 148	160
6.36 Methyl 7-(4-(4-(<i>tert</i> -butoxy)-4-oxobutyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylate 151	161
6.37 4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid, trifluoroacetic acid salt 152	162
6.38 4-Chloro- <i>N</i> -(1 <i>S</i> ,2 <i>S</i>)-2-hydroxycyclopentyl)butanamide 154	163
6.39 4-Chloro- <i>N</i> -(1 <i>R</i> ,2 <i>R</i>)-2-hydroxycyclopentyl)butanamide 155	164
6.40 Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-((<i>trans</i>)-2-hydroxycyclohexyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 158	165
6.41 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxocyclohexyl)amino)-butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 159	166
6.42 4-Chloro- <i>N</i> -(<i>trans</i>)-2-hydroxycyclohexyl)butanamide 160	167
6.43 4-Azido- <i>N</i> -(<i>trans</i>)-2-hydroxycyclohexyl)butanamide 161	168
6.44 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((<i>trans</i>)-2-hydroxycyclohexyl)amino)-4-oxobutyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 162	169
6.45 1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(4-oxo-4-((2-oxocyclohexyl)amino)butyl)-1 <i>H</i> -1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 163	170

7 References

171

1 Nomenclature

<i>J</i>	Coupling constant in Hz
<i>m/z</i>	Mass to charge ratio in Daltons
<i>p</i> -TsOH	<i>p</i> -Toluenesulfonic acid
<i>R_f</i>	Retention factor
Ac	Acetate
AIP	Autoinducing peptide
aq.	Aqueous
atm	Atmosphere(s)
BHL	Butyryl homoserine lactone = C ₄ -HSL 2
Boc	<i>tert</i> -Butyloxycarbonyl
Cip	Ciprofloxacin
CipMe	Methyl ciprofloxacin
conc.	Concentrated
COSY	Correlation spectroscopy
d	Day(s)
Da	Daltons
DBU	1,8-Diazabicyclo[5.4.0]undec-7-ene
DIPEA	<i>N,N</i> -Diisopropylethylamine
DMAP	4-Dimethylaminopyridine
DMF	Dimethylformamide
DMP	Dess-Martin periodinane
DMSO	Dimethylsulfoxide
EDC	1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide
eq.	Equivalents
ESI	Electrospray ionization
Et	Ethyl
EtOAc	Ethyl acetate
FT	Fourier transform
h	Hour(s)
HCTL	Homocysteine thiolactone

HHQ 2-Heptylquinolin-4(1H)-one

HMBC Heteronuclear multiple-bond correlation spectroscopy

HMQC Heteronuclear multiple-quantum correlation spectroscopy

HOBr 1-Hydroxybenzotriazole

HRMS High resolution mass spectroscopy

HSL Homoserine lactone

Hz Hertz

IR Infrared

LCMS Liquid chromatography mass spectroscopy

LCT Liquid chromatography time-of-flight

lit. Literature value

LRMS Low resolution mass spectroscopy

m.p. Melting point

Me Methyl

MIC Minimum inhibitory concentration

min Minute(s)

mol Mole(s)

Ms Methanesulfonyl

NMR Nuclear magnetic resonance

OdDHL *N*-(3-Oxododecanoyl)-homoserine lactone = 3-oxo-C₁₂-HSL **3**

P.E. Petroleum ether

PAI-1 *Pseudomonas* autoinducer 1 = 3-oxo-C₁₂-HSL **3**

PAI-2 *Pseudomonas* autoinducer 2 = C₄-HSL **2**

Pd/C Palladium on carbon

PQS *Pseudomonas* Quinolone Signal

Q-TOF Quadrupole time-of-flight

QS Quorum sensing

QSM Quorum sensing molecule

r.t. Room temperature

s Second(s)

SAM *S*-adenosyl-L-methionine

SAR Structure activity relationship

sat. Saturated

sp. Species

TBAF Tetrabutylammonium fluoride

TBDMSCl *tert*-Butyldimethylsilyl chloride

TBDMSOTf *tert*-Butyldimethylsilyl trifluoromethanesulfonate

TEA Triethylamine

TFA Trifluoroacetic acid

THF Tetrahydrofuran

THPTA Tris(3-hydroxypropyltriazolylmethyl)amine

TLC Thin layer chromatography

TMS Trimethylsilyl

UV Ultraviolet

2 Introduction

2.1 Antibiotic resistance

Antibiotics add, on average, twenty years to a person's life.¹ However, antibiotic resistance is increasing alarmingly and is now recognised as a major threat to global health.^{1,2} Antibiotic discovery had its heyday in the 1940s to 60s, which saw the discovery of many new classes of antibiotic. Since then, the rate of discovery of new classes has slowed and resistance to existing treatments has increased.

The story of how Alexander Fleming discovered penicillin by accidentally allowing a Petri dish containing *Staphylococcus aureus* to become contaminated with *Penicillium* mould whilst he was on holiday in Suffolk¹ is well known to many scientists. The initial serendipitous discovery of penicillin occurred in 1928 and was reported in 1929,³ but it was not until 1943 that the drug was mass produced thanks to the research of Ernst Chain and Howard Florey. Unfortunately, bacterial resistance to penicillin was being found in hospitals by the late 1940s.^{4,5} This alarmingly quick emergence of resistance is a common phenomenon for antibiotics (see Table 1) as bacteria have multiple resistance mechanisms against antibacterial agents. These mechanisms can be broken down into five main categories:

1. The bacterium may inactivate the drug before it can cause damage, for example the hydrolysis of β -lactam antibiotics such as penicillin by β -lactamase enzymes.
2. The bacterium may produce a membrane, cell wall or biofilm which does not allow the drug to pass through, for example biofilm formation may allow bacterial resistance to antibiotics to increase 1000-fold compared with bacteria in suspension culture.⁶
3. The bacterium may pump antibacterial molecules out of its cell membrane using efflux pumps, for example the mexAB and mexXY pumps used by *Pseudomonas aeruginosa*.⁷
4. Mutations may cause the target of the antibacterial molecule to alter such that the molecule no longer effectively binds the target, for example the alteration of penicillin binding proteins which are involved in the final stages of peptidoglycan biosynthesis in the cell walls of MRSA and other penicillin-resistant bacteria.⁸
5. The bacterium may switch to using a metabolic pathway which does not involve the target of the anti-bacterial molecule, for example sulfonamide resistance may be achieved by taking in folic acid from the environment rather than synthesising it using *p*-aminobenzoic acid - a process which is blocked by sulfonamides.⁹

Antibiotic	Introduction	Resistance
Sulfonamides	1930s	1940s
Penicillin	1943	1946
Streptomycin	1943	1959
Chloramphenicol	1947	1959
Tetracycline	1948	1953
Erythromycin	1952	1988
Vancomycin	1956	1988
Methicillin	1960	1961
Ampicillin	1961	1973
Trimethoprim	1962	1972
Cephalosporins	1960s	late 1960s
Ciprofloxacin	1987	1988
Linezolid	2000	1997
Daptomycin	2003	2005

Table 1: A timeline of when various antibiotics were first introduced and when resistance to them first appeared.^{10–15}

2.2 Quorum sensing

A quorum is defined as ‘A fixed minimum number of members of an assembly or society that must be present at any of its meetings to make the proceedings of that meeting valid.’¹⁶ A similar concept is used in bacterial signalling, whereby group behaviour is only triggered when a certain minimum concentration of bacteria has been reached. Examples of group behaviour include bioluminescence, the production of virulence factors and biofilm formation. It is advantageous for bacteria to coordinate such behaviours as they would be ineffective, and therefore a waste of resources, when carried out by a single bacterium but effective when carried out as a group. The process by which bacteria determine the concentration of similar bacteria in their vicinity, and act on that information, is known as quorum sensing.

Quorum sensing has since been observed in many species of bacteria, including *Vibrio fischeri*, *P. aeruginosa*, *Agrobacterium tumefaciens*, *Erwinia carotovora*, *Streptococcus pneumoniae*, *Bacillus subtilis*, *Staphylococcus aureus*, *Vibrio harveyi*, *Escherichia coli*, *Myxococcus xanthus*, *Salmonella enterica*, *Yersinia enterocolitica*, *Aeromonas* sp. and *Acinetobacter* sp.^{17–26} Many of these bacteria are significant causes of disease and death in humans, for example, in a typical year in the U.S. *P. aeruginosa* causes 6,700 multidrug-resistant infections and 440 deaths, methicillin-resistant *S. aureus* causes 80,500 severe infections and 11,300 deaths and non-typhoidal *Salmonella* causes 1.2 million illnesses, 23,000 hospitalisations and 450 deaths.²

2.2.1 *Vibrio fischeri*

The first example of quorum sensing was discovered in *V. fischeri*, a symbiotic bacterium that produces bioluminescence in the photophore of the Hawaiian bobtail squid, *Euprymna scolopes*^{17,25,26} (see Figure 1). This bacterium receives amino acids^{27,28} from its host in exchange for producing light which the squid uses for counterillumination, to camouflage itself.²⁹

If a low population of *V. fischeri* were present in the photophore, the light that the bacteria could produce would be insufficient to provide counterillumination. Therefore, the bacteria conserve resources by not producing light. However, if there is a high population of *V. fischeri* it is useful for them all to produce light, as this incentivises the squid to provide them with nutrients.



Figure 1: ‘Euprymna scolopes, South shore of Oahu, Hawaii’ by Jamie Foster. Licensed under CC BY-SA 3.0 via Commons.

V. fischeri uses the LuxR-LuxI system to sense cell density. This system is seen as a paradigm of quorum sensing, and a simplified explanation of it is presented to show typical features of such a system (see Figure 2).

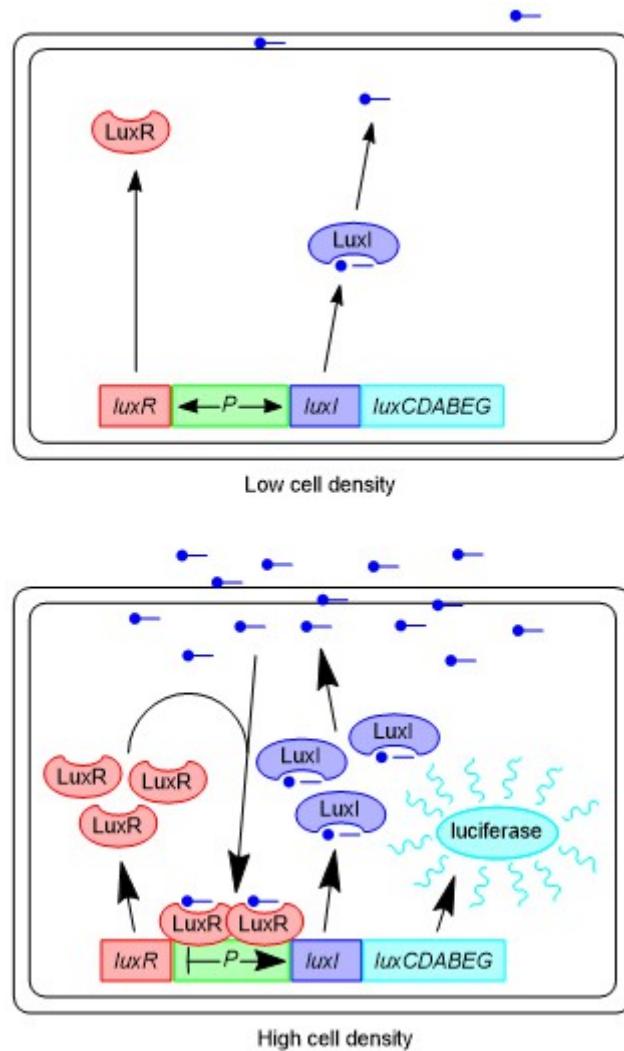


Figure 2: The LuxR-LuxI quorum sensing system in *V. fischeri*.

V. fischeri senses cell concentration by the detection of 3-oxo-C₆-HSL **1**³⁰ (see Figure 3), a freely diffusible³¹ molecule which is synthesised by LuxI^{32,33} and secreted by all *V. fischeri* cells³⁴ at a low basal level.¹⁷ When the

bacterial population density, and hence the concentration of 3-oxo-C₆-HSL **1**, reaches a threshold, 3-oxo-C₆-HSL **1** binds to LuxR,³⁵⁻³⁷ a receptor which is also synthesised at a low basal level.

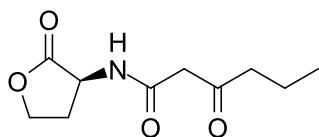


Figure 3: 3-oxo-C₆-HSL **1**.

The LuxR complex binds to the *lux* operator, upregulating production of LuxI and hence 3-oxo-C₆-HSL **1**, and luciferase enzymes and hence blue-green light.³⁸⁻⁴⁰ Production of more 3-oxo-C₆-HSL **1** enables a positive feedback loop, reinforcing the effect of high population density on 3-oxo-C₆-HSL **1** concentration and hence light production. This is the reason that 3-oxo-C₆-HSL **1** is known as an autoinducer.

The system also contains a negatively feedback loop to avoid excessive expression of proteins: at high concentrations of 3-oxo-C₆-HSL **1** production of LuxR is inhibited.⁴¹ Such balancing effects, as well as interactions with other quorum sensing and metabolic systems, are very common.

2.2.2 *Pseudomonas aeruginosa*

Another well-studied example of quorum sensing is in *P. aeruginosa*.⁴²⁻⁴⁴ *P. aeruginosa* is a Gram-negative opportunistic pathogen which typically infects immunocompromised individuals such as those with cystic fibrosis, neutropenia and AIDS. It can infect the pulmonary and urinary tracts as well being the most frequent cause of burn wound infections and the most frequent coloniser of medical devices such as catheters.⁴⁵

P. aeruginosa has a low susceptibility to many antibiotics and readily acquires antibiotic resistance by mutation or horizontal gene transfer.⁴⁶ It is difficult for antibiotics to cross into cells due to low cell membrane permeability⁴⁷ and biofilm formation,⁴⁸ and they are pumped out again by its multiple chromosomally encoded multidrug efflux pumps.⁷ *P. aeruginosa* biofilms are more resistant to many drugs including ciprofloxacin **24** and trimethoprim **25** compared with planktonic cells.^{48,49} This high level of antibiotic resistance makes *P. aeruginosa* an important target for drug discovery.

Quorum sensing in *P. aeruginosa* involves a complex interplay of five signalling molecules (see Figure 4) and various proteins (see Figure 5).⁴²⁻⁴⁴ These can be broken down into three main, interacting systems: Las, Rhl and Pqs.

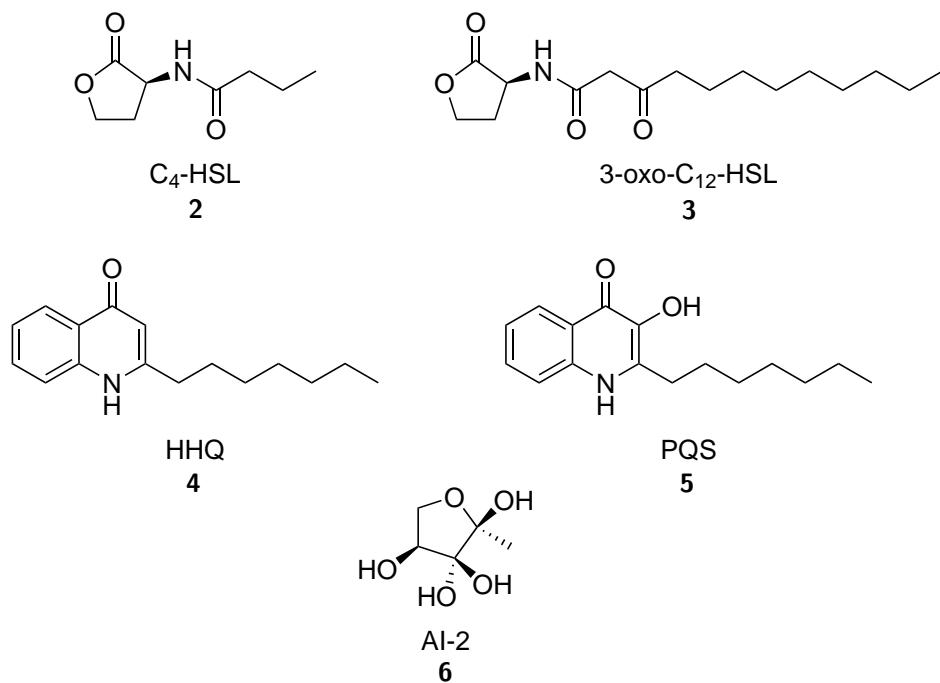


Figure 4: *P. aeruginosa* autoinducers.

In the Las system, LasI⁵⁰ synthesises the 3-oxo-C₁₂-HSL **3**⁵¹ autoinducer. 3-oxo-C₁₂-HSL **3** binds LasR,⁵² and this complex upregulates the production of LasI⁵³ (thus causing autoinduction) as well as alkaline protease,⁵⁴ elastase,⁵² exotoxin A,⁵⁴ HCN⁵⁵ and LasA protease.⁵⁶ The LasR complex is also important in late-stage biofilm formation,²² and upregulates the Rhl⁵⁷ and Pqs systems.^{58,59}

In the Rhl system, RhlI⁶⁰ synthesises the C₄-HSL **2**⁶¹ autoinducer. C₄-HSL **2** binds RhlR,⁶² and this complex upregulates the production of RhlI⁵³ (again causing autoinduction), alkaline protease,⁶³ elastase,⁶⁰ haemolysin,⁶³ HCN,^{55,63} LasA protease,⁶⁰ LecA,⁶⁴ pyocyanin^{60,63} and rhamnolipids.⁶⁰ The RhlR complex also downregulates the Pqs system.^{59,65} The Rhl system is controlled by both the Las and Pqs systems, as production of both RhlR and RhlI is upregulated by the LasR complex⁵⁷ and production of both RhlR is upregulated by the PqsR complex.⁶⁶

In the Pqs system, the main autoinducer, PQS **5**,⁶⁷ is synthesised by multiple enzymes. PhnAB,⁶⁸ PqsA, PqsBC, PqsD^{69,70} and PqsE^{71,72} produce the precursor HHQ **4**, and PqsH converts HHQ **4** to PQS **5**. PQS **5**⁵⁹ or HHQ **4** binds PqsR,⁷³ and either complex can upregulate the synthesis of HHQ **4** causing autoinduction. The PqsR-PQS complex upregulates the production of chitinase,⁷⁴ elastase,⁶⁷ HCN,⁷⁴ LecA,⁷⁵ pyocyanin^{58,76} and pyoverdine,⁷⁶ as well as increasing biofilm production⁷⁵ and vesicle formation.⁷⁷ The PqsR-PQS complex also upregulates production of RhlR, so the Pqs system has control over the Rhl system.⁶⁶ The Pqs system is controlled by both the Las and Rhl systems, as production of PqsR⁵⁹ and PqsH⁵⁸ is upregulated by the LasR complex and production of PqsA, PqsBC, PqsD, PqsE⁶⁵ and PqsR⁵⁹ is downregulated by the RhlR complex.

add
num-
bers
man-
ually
when
sorted

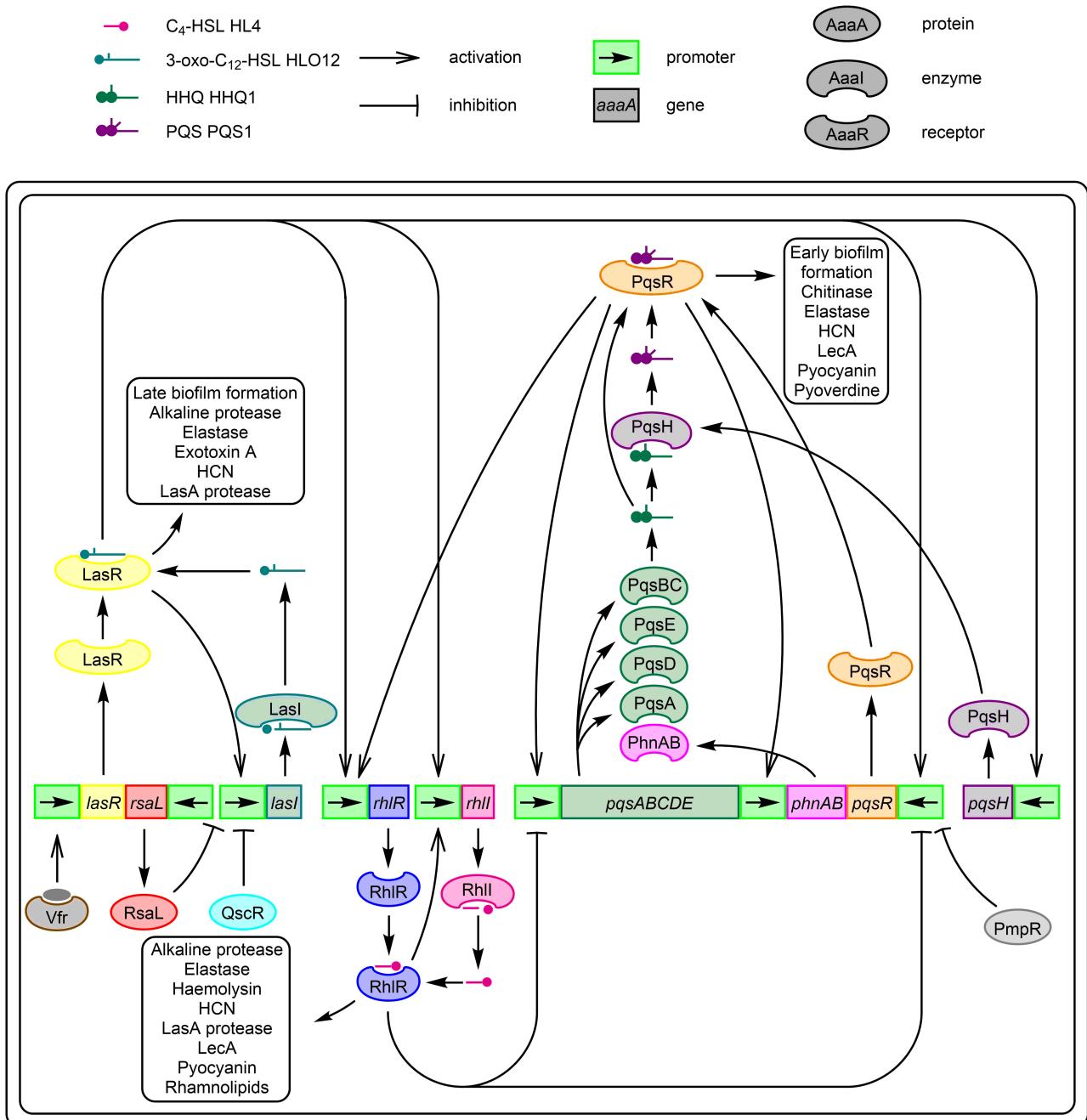


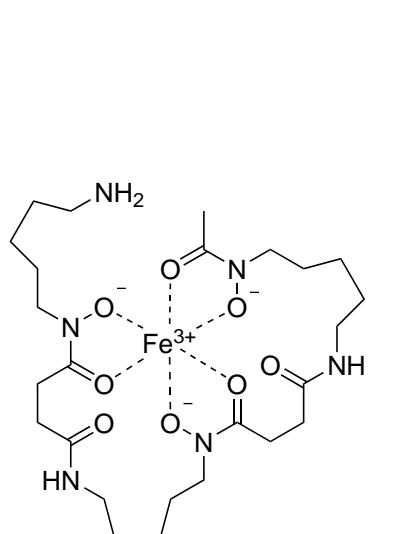
Figure 5: Quorum sensing in *P. aeruginosa*.⁴²⁻⁴⁴

In addition to the above systems, AI-2 (see Figure 4), an interspecies signalling molecule,⁷⁸ is known to increase biofilm production and virulence in *P. aeruginosa*.^{79,80} This is thought to be achieved by interaction with the Las and Rhl systems, but the exact mechanism is not known.

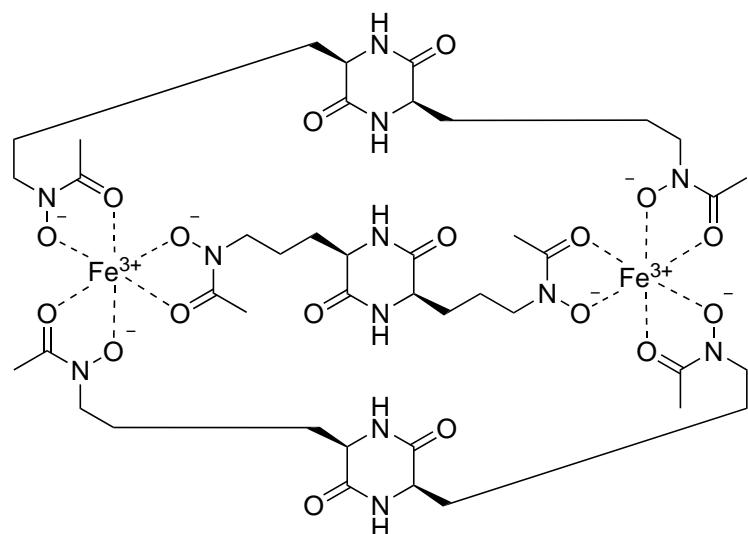
In summary, *P. aeruginosa* uses the autoinducers shown in Figure 4 as part of three interacting quorum sensing systems to coordinate virulence and biofilm production, and this makes these autoinducers interesting therapeutic targets. Quorum sensing has been successfully targeted using many different modulators,^{43,81} but this study takes a slightly different approach. Inspired by the success of various siderophore-antibiotic conjugates (see 2.5), a library of autoinducer-antibiotic conjugates was synthesised, in the hope that the importance of autoinducers in harmful cellular behaviours would lead to increased activity of the conjugates (see 2.6).

2.3 Siderophores

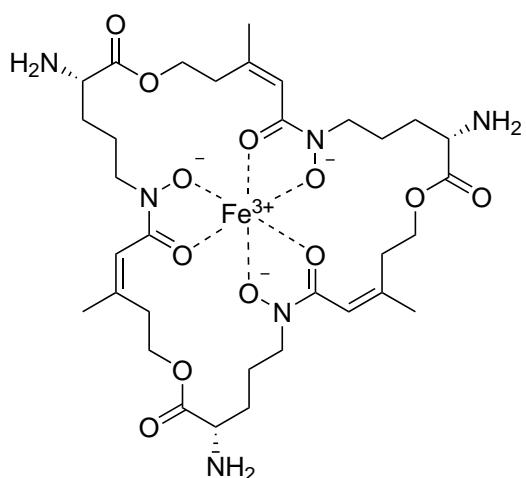
Siderophores are peptides or small molecules used by microorganisms to chelate iron for the purposes of ‘iron mining’.⁸² Soluble iron is often scarce but it is crucial for many cellular processes including respiration and DNA synthesis. Siderophores are synthesised by the microorganisms and secreted into the extracellular environment where they bind to Fe^{3+} , often with exceptionally high affinities. The iron-bound siderophores are then brought back into the cell by active transport and the iron is released, either by reduction of the Fe^{3+} to Fe^{2+} or by enzymatic degradation of the siderophore. Siderophores have a wide range of structures (see Figure 6 and Figure 7), possibly so one species can avoid its siderophores being taken up by another species.⁸³



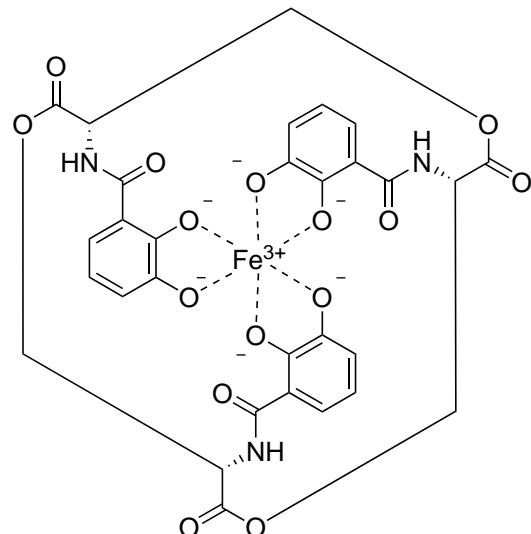
Deferoxamine B
7



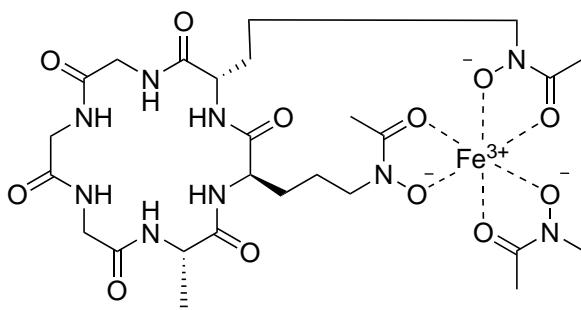
Rhodotorulic acid
8



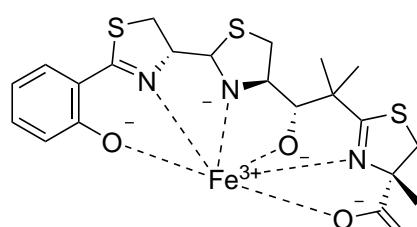
Fusarinine C
9



Enterobactin
10



Ferrichrome
11



Yersiniabactin
12

Figure 6: Iron-siderophore complexes: Deferoxamine **7**⁸⁴ (*Streptomyces pilosus* and *Streptomyces coelicolor*), rhodotorulic acid **8**⁸⁵ (*Rhodotorula pilimanae*), fusarinine C **9**⁸⁶ (*Fusarium roseum*), enterobactin **10**⁸⁴ (*Escherichia coli* and enteric bacteria), ferrichrome **11**⁸⁷ (*Ustilago sphaerogena*, *U. maydis*, *Aspergillus niger*, *A. quadricinctus*, *A. duricaulis* and *Penicillium resticolum*), yersiniabactin **12**⁸⁴ (*Yersinia pestis*).

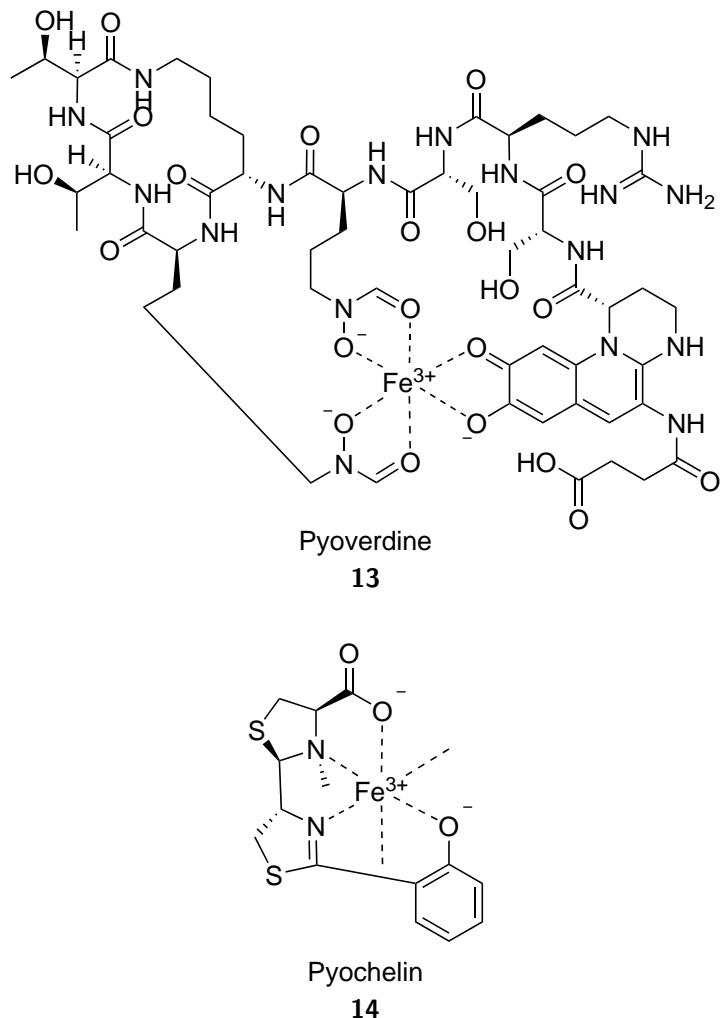


Figure 7: Iron-siderophore complexes: Pyochelin **13**⁸⁸ (*P. aeruginosa*), Pyoverdine **14**⁸⁴ (*P. aeruginosa*). Note that pyoverdine **14** is a tetradentate ligand, hence the iron ion has two sites which can bind other ligands.

2.4 Sideromycins

Siderophore-antibiotic conjugates are produced naturally by some bacteria and are known as sideromycins⁸⁹ (see Figure 8). Bacteria produce these molecules to attack other bacteria by hijacking their siderophore uptake mechanisms to introduce toxic compounds.

For example, albomycin **15** (see Figure 8) is a sideromycin produced by *Actinomyces subtropicus* and *Streptomyces griseus*^{90,91} which has been used to treat infections caused by various bacteria including *Yersinia enterocolitica* and *Streptococcus pneumoniae* in mice and humans.^{92,93} Albomycin **15** contains a siderophore coupled to a nucleoside antibiotic via a peptide linker. The siderophore section is structurally similar to ferrichrome **11** (see Figure 6), a siderophore produced by various fungi, but also taken up by bacteria including *Escherichia coli*, *Salmonella typhimurium* and *P. aeruginosa*.^{87,94} It has been shown that because of the structural similarity to ferrichrome **11**, *E. coli* will also take up albomycin **15**.⁹⁰ The linker is hydrolysed in the cytoplasm of the *E. coli*, releasing the active nucleoside antibiotic. This leads to 500-fold concentration of the antibiotic within the *E. coli* cells, enough to have significant effect on growth.

The success of albomycin⁹² and other sideromycins such as salmycin A^{82,95,96} and ferrimycin A1^{97,98} has served as encouragement to many researchers to explore synthetic siderophore-antibiotic conjugates, which will be discussed in the next section.

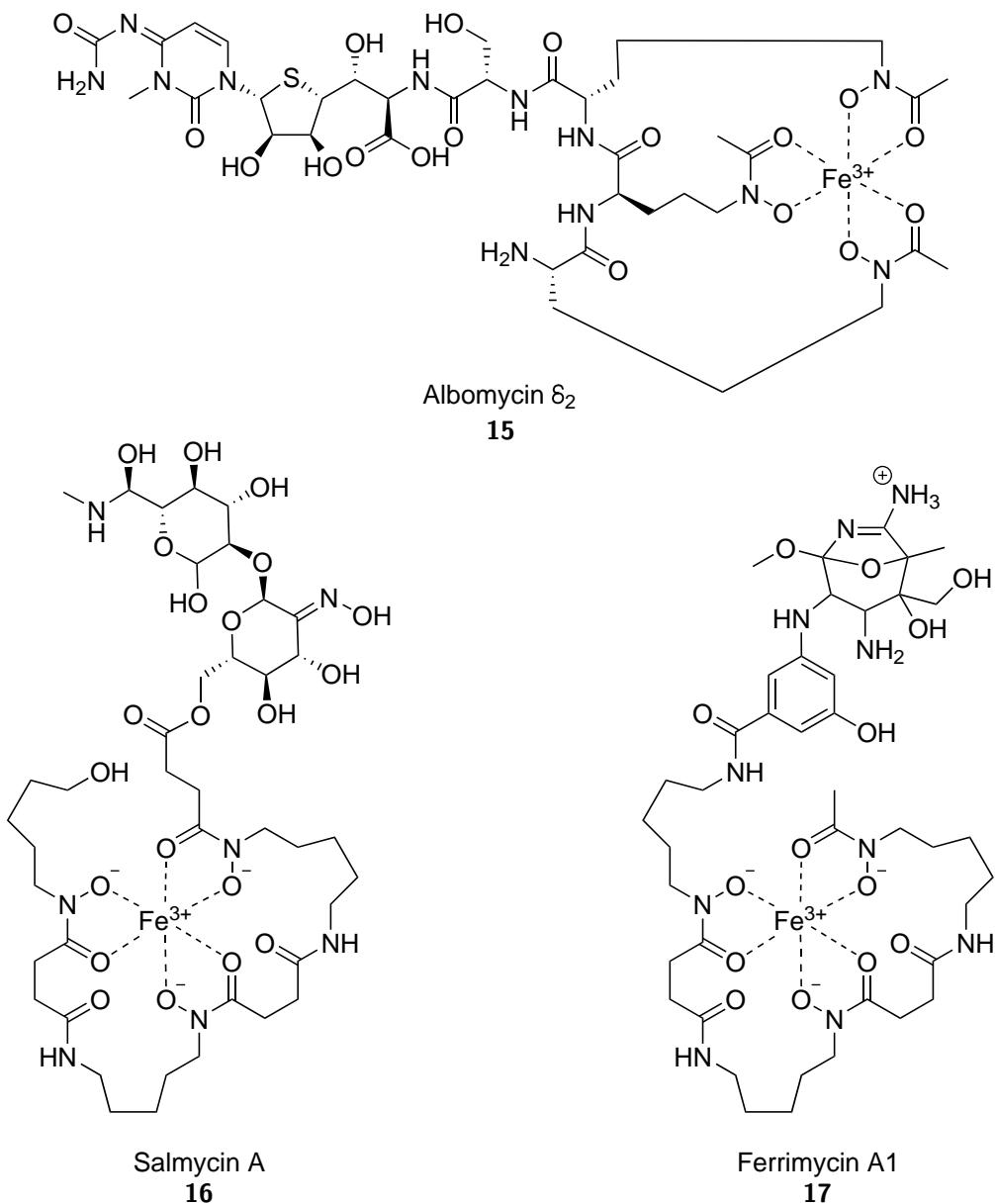


Figure 8: Iron-sideromycin complexes: Albomycin **15**^{82,99} (*Actinomyces subtropicus* and *Streptomyces griseus*), salmycin A^{82,95,96} (*Streptomyces violaceus*) and ferrimycin⁸² (*Streptomyces griseoflavus*).

2.5 Synthetic siderophore-antibiotic conjugates

Sideromycins served as inspiration for the design, synthesis and biological evaluation of a wide range of synthetic siderophore-antibiotic conjugates.⁸⁹ Antibiotics used include β -lactams,^{100–102} nucleosides,¹⁰³ glycopeptides¹⁰⁴ and macrolides.¹⁰⁵ Sideromycin-fluoroquinolone conjugates have also been studied by several groups,^{106–108} including conjugates with linkers which can be cleaved^{107,108} in a similar manner to albomycin.⁹⁰ Some of these showed comparable activity to the parent antibiotic, but it is not clear whether attachment of the siderophore improved uptake or whether the conjugates acted as classical prodrugs.

β -lactam-sideromycin conjugates have been more widely investigated and show good activity *in vitro*, however, resistance can evolve by loss of the TonB transporter or of the relevant siderophore receptor, e.g. Cir and Fiu for catecholate siderophores or FhuA for hydroxamate siderophores.⁸⁹ Recently a conjugate (Ent-Amp **18**, see Figure 9) of enterobactin and ampicillin joined using a copper(I)-catalyzed azide-alkyne cycloaddition has been shown to have increased activity against pathogenic *E. coli* when compared to native ampicillin.¹⁰⁹ Other work has focused on monocyclic β -lactams, for example pirazmonam **19** and U-78608 **20**, which show high po-

tency against Gram-negative bacteria including *P. aeruginosa*.^{110,111} Monocyclic β -lactams are generally fairly stable to β -lactamase activity, which is an advantage compared with many bicyclic β -lactams.

Three siderophore-antibiotic conjugates are reported as being in clinical trials:¹¹² MC-1 **21**,¹¹³ BAL30072 **22**⁸⁹ (see Figure 9) and cefiderocol **23**^{114,115}.

MC-1 **21** is reported as being "in clinical phases of development",¹¹² but no reports of studies in humans could be found. However, experiments in mice have been promising.¹¹³ BAL30072 **22** is a siderophore- β -lactam conjugate which showed initial promise as it is a poor substrate for β -lactamases, and resistance due to loss of transport proteins is infrequent.⁸⁹ However, it is unclear whether it will progress further in trials as it causes liver toxicity.¹¹⁶ Cefiderocol **23** is a cephalosporin-catechol conjugate in phase 1 trials. Recent results indicate that 'single and 35 multiple intravenous doses of cefiderocol at up to 2000 mg were well tolerated in healthy 36 subjects'.¹¹⁵

These examples show that siderophore-antibiotic conjugates are a promising strategy to deliver antibiotics across bacterial membranes, but it is worth noting that conjugation to a siderophore may lead to loss of activity, or resistance may be acquired by loss of transport proteins. Encouragingly though, albomycin **15**-resistant mutants have been shown to be less virulent,⁹³ indicating that bacteria may lose out either by susceptibility to the antibiotic or by loss of fitness due to decreased iron transport.

Building on these positive examples, it is hoped that the strategy of conjugating a molecule which is important for virulence¹¹⁷ with an antibiotic can be extended to conjugates of autoinducers and antibiotics in a similar 'Trojan horse' approach.

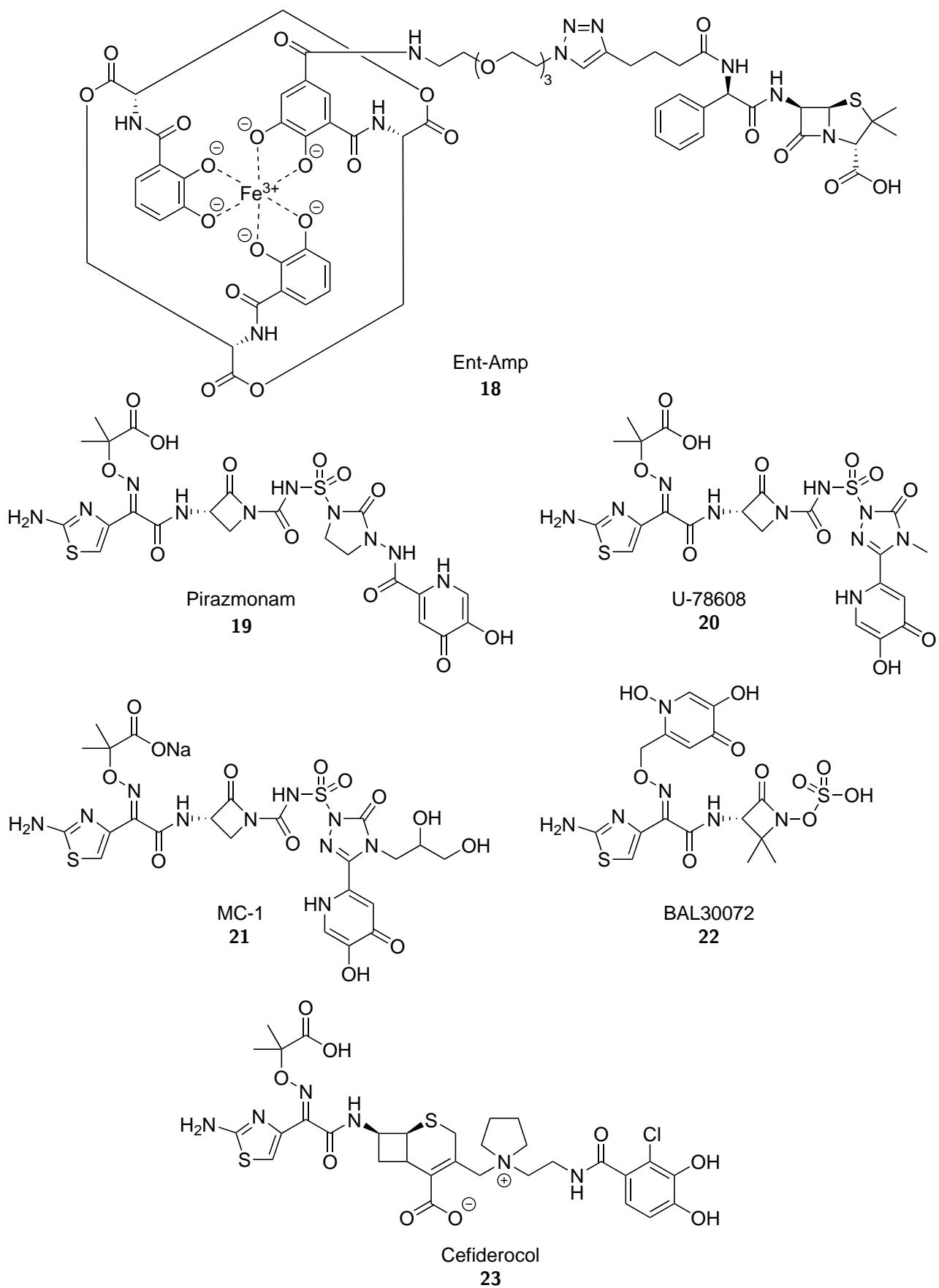


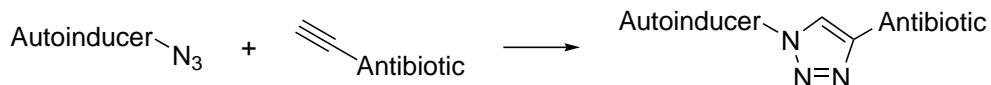
Figure 9: Ent-Amp **18**,¹⁰⁹ pirazmonam **19**,^{110,111} U-78608 **20**,^{110,111} MC-1 **21**,¹¹³ BAL30072 **22**⁸⁹ and cefiderocol **23**.^{114,115}

2.6 Autoinducer-antibiotic conjugates

This study has extended the conjugation strategy discussed above by creating autoinducer-antibiotic conjugates. It was hypothesised that attaching an autoinducer to a known antibiotic could lead to increased cellular retention of the antibiotic, and could potentially restore function against resistant strains. The work is divided into two main sections. The first section focuses on conjugates of three *P. aeruginosa* autoinducers (see Figure 4) with ciprofloxacin and trimethoprim (see Figure 10). The second section focuses on conjugates of homoserine lactone analogues with ciprofloxacin (see 2.7).

2.6.1 Synthesis of the conjugates

A copper(I)-catalysed azide-alkyne cycloaddition,^{118,119} commonly referred to as a click reaction (although this is a more general term), was used to join each combination of autoinducer and antibiotic together (see Scheme 1). The autoinducers were functionalised with azide groups, and the antibiotics with alkynes. This modular approach would allow the library to be expanded easily by adding more autoinducers or antibiotics, or indeed other groups such as siderophores, fluorescent or affinity tags, or resin beads.



Scheme 1: The construction of the triazole-linked autoinducer-antibiotic conjugate library using a copper(I)-catalysed azide-alkyne cycloaddition.

2.6.2 Autoinducers

The *P. aeruginosa* autoinducers (see Figure 4) were chosen as *P. aeruginosa* is a significant human pathogen which shows high antibiotic resistance and utilises quorum sensing to coordinate pathogenic behaviours (see 2.2.2). Specifically, C₄-HSL **2**, HHQ **4** and PQS **5** derivatives were chosen as they were considered to be the most synthetically tractable.

2.6.3 Autoinducer efflux

Autoinducers must be exported from the cell in order to be used for intercellular communication, and the five known *P. aeruginosa* autoinducers are exported by various different transport mechanisms. The mechanism is not well known for HHQ **4** or AI-2 **6**, but it is known that PQS **5** is exported in vesicles,¹²⁰ C₄-HSL **2** passively diffuses in and out of cells,¹²¹ and 3-oxo-C₁₂-HSL **3** is taken up passively, accumulates in the cell membrane and is actively pumped out by efflux pumps. The difference in transport mechanism for C₄-HSL **2** and 3-oxo-C₁₂-HSL **3** is thought to be largely due to chain length rather than the 3-oxo modification, as a shorter-chain version, 3-oxo-C₆-HSL **1** has been shown to be freely diffusible through *V. fischeri* membranes.³¹

3-oxo-C₁₂-HSL **3** is exported primarily via the MexAB-OprM efflux system.^{7,122} The increased removal of 3-oxo-C₁₂-HSL **3** from the cell by upregulation of the MexAB-OprM system leads to decreased production of additional 3-oxo-C₁₂-HSL **3** (as the positive feedback loop is disrupted, see 2.2.2), and hence decreased production of pyocyanin, elastase and casein protease. It is expected that MexAB-OprM upregulation would also disrupt biofilm formation as a decrease in 3-oxo-C₁₂-HSL **3** levels would disrupt Las-mediated quorum sensing,¹²³ but no direct studies of this could be found.

2.6.4 Antibiotics

Ciprofloxacin **24** and trimethoprim **25** (see Figure 10) were chosen as the antibiotic sides of the conjugates.

Ciprofloxacin **24** is second-generation fluoroquinolone antibiotic used to treat both Gram-positive and Gram-negative bacterial infections including *P. aeruginosa*.^{124,125}

Trimethoprim (see Figure 10) is a dihydrofolate reductase inhibitor used primarily to treat bladder infections.¹²⁶ It is active against several significant human pathogens including *Streptococcus pneumoniae* and *Haemophilus influenzae*, but not against *P. aeruginosa*. It was primarily chosen in this study as it was considered easy to functionalise, but also to test the feasibility of creating antibiotic activity against *P. aeruginosa*.

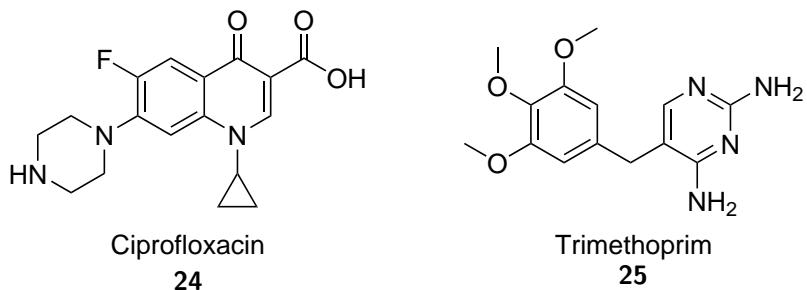


Figure 10: The antibiotics used in this section.

2.6.5 Antibiotic efflux

Ciprofloxacin **24** enters *P. aeruginosa* by diffusion,¹²⁷ but is pumped out by efflux pumps.¹²⁸ In the planktonic state several efflux pumps are known to pump out ciprofloxacin **24**, including MexAB–OprM, MexCD–OprJ, MexEF–OprN, MexXY–OprM, MexJK–OprM and MexVW–OprM.⁷ However, in biofilms only MexEF–OprN has an effect.¹²⁹

Trimethoprim **25** is mainly exported by the MexAB–OprM,¹³⁰ MexCD–OprJ¹³¹ and MexEF–OprN¹³² multidrug efflux systems^{7,133} in the planktonic state. It is not known which pumps are used to export trimethoprim **25** from biofilms, but biofilms do show increased resistance to it.⁴⁹

2.6.6 Conjugate efflux and antibiotic action

There are two ways in which the conjugates could disrupt *P. aeruginosa* growth:

1. *P. aeruginosa* could develop resistance to an autoinducer-antibiotic conjugate by upregulation of its export mechanism, but this would also lead to increased export of the native autoinducer, thus disrupting the quorum sensing system and hence biofilm formation and virulence.^{42,122,123} For HSL conjugates this would mean upregulation of the MexAB–OprM pump, as this is the pump used for export of 3-oxo-C₁₂-HSL **3**.^{7,122} For PQS conjugates this would mean upregulation of vesicle formation.¹²⁰
2. The autoinducer section could make the conjugate a poor substrate for the antibiotic section's usual efflux mechanism, leading to accumulation of the conjugate within cells and hence increased antibacterial activity. For autoinducer-ciprofloxacin conjugates acting on planktonic *P. aeruginosa* this would mean the conjugate being a poor substrate of the various efflux pumps listed in the previous section. For autoinducer-ciprofloxacin conjugates acting on biofilms this would mean the conjugate being a poor substrate of MexEF–OprN (the sole exporter of ciprofloxacin **24** in biofilms¹²⁹ and not an exporter of HSLs **2** or **3**, or PQS **5**⁷). This mechanism could in principle work for trimethoprim **25** as well, but it is not known which pumps are active against this antibiotic in biofilms.

2.7 Autoinducer analogue-ciprofloxacin conjugates

Following on from the library of compounds based on *P. aeruginosa* autoinducers, a series of conjugates based on *analogues* of HSL were planned. This strategy was inspired by a paper¹³⁴ and patent¹³⁵ by Ganguly *et al.*, who synthesised and characterised a conjugate **111** of methyl ciprofloxacin with homocysteine thiolactone (see Figure 11). Homocysteine thiolactone is an analogue of homoserine lactone with the ring oxygen replaced by sulfur, and has been used as the head group in several other known quorum sensing modulators.^{34, 136–142}

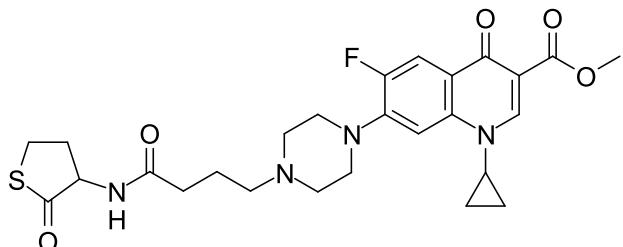


Figure 11: The HCTL-CipMe conjugate **111** studied by Ganguly *et al.*^{134, 135}

As part of their characterisation of the HCTL-CipMe conjugate **111**, Ganguly *et al.* found the minimum inhibitory concentration (MIC) of the conjugate in *P. aeruginosa* under standard planktonic conditions. The MIC was found to be ten times higher for the conjugate vs. ciprofloxacin (50 vs. 5 μm), indicating that the conjugate was less effective than ciprofloxacin under planktonic conditions.

Ganguly *et al.* then investigated the effect of the conjugate on biofilms. The conjugate and ciprofloxacin were first added to dilute *P. aeruginosa* liquid culture at 25 μm . As expected, the culture failed to grow and form biofilm in the presence of ciprofloxacin, but did grow in the presence of the conjugate **111**. They then incubated cultures for 24 h, to allow biofilms to grow, before adding the compounds. In contrast, they found that the conjugate **111** disrupted the biofilm more effectively than ciprofloxacin. When the biofilm was grown for 48 or 72 hours the conjugate had similarly disruptive effects, whereas ciprofloxacin ‘did not show any significant antibacterial activity’.

These results are exciting as they hint that an autoinducer conjugate might be able to combat an established *P. aeruginosa* infection more effectively than the unmodified antibiotic. Ganguly *et al.* suggest that their conjugate is more effective than ciprofloxacin in penetrating biofilms, and/or better at avoiding being pumped out by multidrug efflux pumps. They posit that this could be due to the thiolactone head, as they also showed that unconjugated C₄-HCTL **26** (see Figure 12) has ‘either enhanced uptake or functional activity’ when compared with C₄-HSL **2**.

It is possible that the conjugate **111** has higher activity against biofilms when compared with ciprofloxacin **24** because conjugate **111** avoids being pumped out by multidrug efflux pumps, or selects for the survival of mutants with upregulated efflux pumps, and hence disrupted quorum sensing systems (see 2.6.6).

While one might expect the conjugate **111** to behave like C₄-HSL **2**, and hence passively diffuse in and out of cells, it is possible that its transport more closely resembles that of 3-oxo-C₁₂-HSL **3**. 3-oxo-C₁₂-HSL **3**’s accumulation in membranes and interaction with efflux pumps is thought to be based primarily on tail chain length (see 2.6.3), and the ciprofloxacin half of the conjugate **111** could be seen as a long tail, especially as the carboxylic acid is methylated and hence less polar.

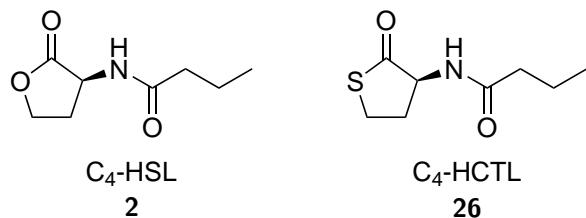


Figure 12: C₄-HSL **2** and C₄-HCTL **26**. Note that Ganguly *et al.* tested the *S* enantiomer of C₄-HCTL **26**, but used a racemic mixture in their HCTL-CipMe conjugate.

While the results found by Ganguly *et al.* show promise, they only test one conjugate, and do not include controls to show that the HCTL group specifically is necessary for the enhanced effect. It was therefore decided to build on this work by synthesising a series of ciprofloxacin conjugates with head groups known as part of quorum sensing modulators.^{81,143}

The activity of the chosen head groups against *P. aeruginosa* receptors when coupled with the native C₄ and 3-oxo-C₁₂ tails is summarised in Table 2. It is hoped that high activity of these molecules should correlate with high activity of their ciprofloxacin conjugates. This is not a comprehensive list of active head groups, and other possible choices are covered in ??.

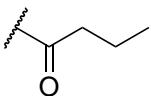
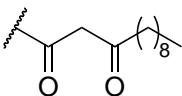
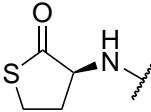
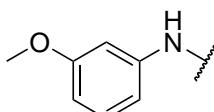
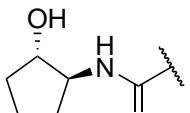
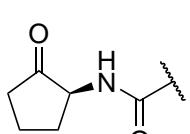
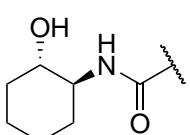
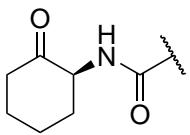
Head group		
	Partial agonist and antagonist against LasR. ¹⁴⁰ Shown to increase biofilm formation in <i>P. aeruginosa</i> . ¹³⁴	Strong agonist against LasR, with comparable activity to the native ligand. ^{137, 138, 140, 144}
	Partial agonist against LasR. ¹⁴³	Strong antagonist against LasR. ¹⁴³
	Poor agonist and antagonist against RhlR. ^{145, 146}	Strong antagonist against LasR. ¹⁴⁵
	Strong agonist against RhlR. ¹⁴⁵ SS enantiomer is more potent. ¹⁴⁶	Partial agonist against LasR. ¹⁴⁵
	Strong agonist against RhlR. ¹⁴⁵ SS enantiomer is more potent, with comparable activity to the native ligand. ¹⁴⁶	Strong agonist against LasR. ^{138, 145} SS enantiomer is more potent, with comparable activity to the native ligand. ¹⁴⁶
	Strong agonist against RhlR. ¹⁴⁵ SS enantiomer is more potent. ¹⁴⁶	Partial antagonist against LasR. ¹⁴⁵ Shown to reduce biofilm formation in <i>P. aeruginosa</i> . ¹⁴⁵

Table 2: Activities of autoinducers containing the chosen head groups when coupled with C₄ or 3-oxo-C₁₂ tails.

Boursier
pre-
release,
check
for
updates

3 Autoinducer-antibiotic conjugates

3.1 Introduction

The first part of this project was focused on producing a library of autoinducer-antibiotic conjugates. *P. aeruginosa* autoinducers were used, in particular C₄-HSL **2**, HHQ **4** and PQS **5** (see Figure 4). Azido derivatives of these compounds were coupled to alkynyl derivatives of antibiotics, specifically ciprofloxacin **24** and trimethoprim **25** (see Figure 10), using a copper(I)-catalysed azide-alkyne cycloaddition.^{118,119}

3.1.1 Azido autoinducer derivatives

The structure-activity relationships in HHQ **4** and PQS **5** have been previously studied,^{147–149} and it was shown various substitutions on the benzene ring could be made without significantly decreasing activity. The 6-azido derivatives (see Figure 13) were chosen for this study as routes to them have previously been found.¹⁵⁰

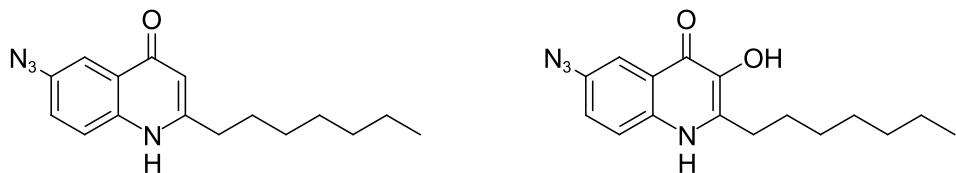


Figure 13: The azido derivatives of HHQ **4** and PQS **5**: **46** and **57**.

Alteration of the lactone group of C₄-HSL **2** and other HSL derivatives is known to significantly decrease activity, especially where the number of H-bond donors or acceptors is altered.⁸¹ Hence, the azide group was included on the tail of C₄-HSL **2**. Acyl tail length is known to play an important role in affinity, so three derivatives of C₄-HSL **2** were synthesised: N₃-C₂-HSL **63**, N₃-C₄-HSL **66** and N₃-C₆-HSL **69** (see Figure 14).

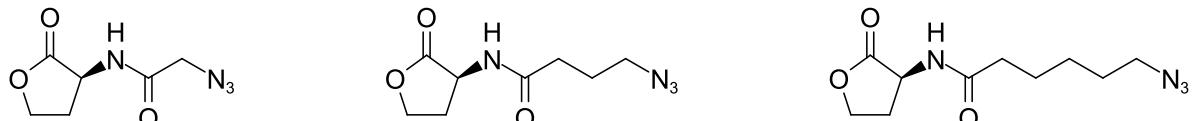


Figure 14: The azido derivatives of C₄-HSL **2**: **63**, **66** and **69**.

3.1.2 Alkynyl antibiotic derivatives

The structure-activity relationships for ciprofloxacin have been investigated¹⁵¹ and modifications at the cyclopropane and piperazine groups were found not to cause loss of activity. It was decided an alkyne tail would be added onto the free NH of the piperazine ring, as this position is more synthetically accessible. Alkynyl ciprofloxacin derivative **76** (see Figure 15) was synthesised in this study (see 3.3.1), and two cleavable alkynyl ciprofloxacin derivatives **98** and **99** were synthesised by Dr Eddy Sotelo and combined with some of the azido HSL derivatives made in this study (see 3.2.3 and 3.4.3).

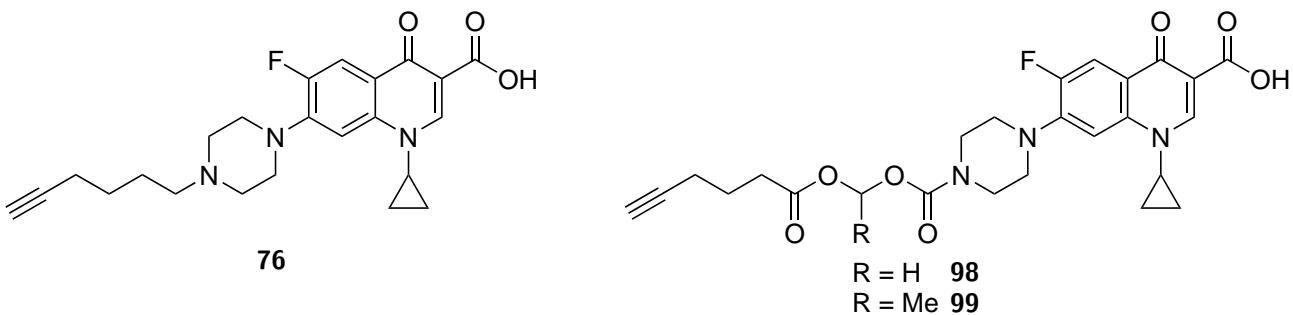


Figure 15: The alkynyl ciprofloxacin derivatives **76**, **98** and **99**.

The choice to of alkyne tail attachment point on trimethoprin **25** (see Figure 16) is based on the use of that same point in a fluorogenic trimethoprim tag synthesised by Jing *et al.*¹⁵²

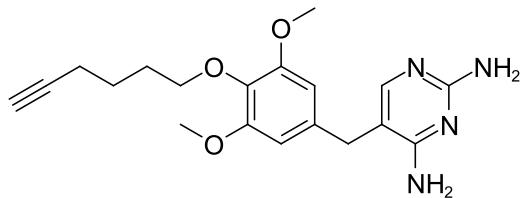


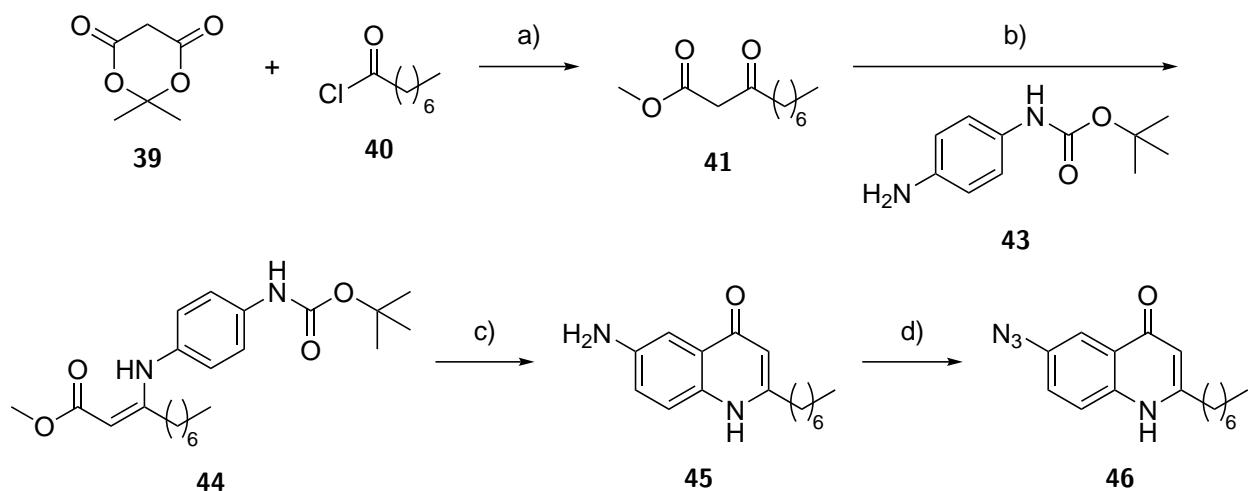
Figure 16: The alkynyl trimethoprim derivative **79**.

3.2 Azido autoinducer derivatives

3.2.1 Synthesis of 6-N₃-HHQ **46**

The synthesis of 6-N₃-HHQ **46** is shown in Scheme 2 and follows a route devised by Baker.¹⁵⁰ Octanoyl chloride **40** was converted to β -Ketoester **41** via a Meldrum's acid adduct.^{153,154} The β -ketoester **41** was condensed with *N*-Boc-*p*-phenylenediamine **43** to form enamine **44**. The disappointing yield of this step was in part due to the reaction proceeding to an equilibrium state rather than to completion, and hence not all of the starting material being consumed; starting materials can be recycled to improve the yield. Alternatively, Baker later found a higher-yielding reaction using a ZrCl₄ catalyst.

The enamine **44** was cyclised with polyphosphoric acid to form amino-HHQ **45** in good yield. The amine group of amino-HHQ **45** was converted to a diazo group by reaction with NaNO₂ and HCl, followed by displacement with NaN₃ to form the final azido-HHQ product **46**.¹⁵⁵



Scheme 2: The synthesis of **46**. a) i) Pyridine, DCM, 0 °C. ii) MeOH, reflux, 66 % over two steps. b) MeOH, reflux, 19 %. c) Polyphosphoric acid, 120 °C, 72 %. d) i) NaNO₂, HCl, H₂O, 0 °C. ii) NaN₃, H₂O, r.t., 46.5 %.

3.2.2 Synthesis of 6-N₃-PQS **57**

The synthesis of 6-N₃-PQS **57** is shown in Scheme 3, and also follows a route devised by Baker.¹⁵⁰ The Weinreb amide **51**⁴³ was prepared from chloroacetyl chloride, followed by attack with heptyl magnesium bromide **48** to form 1-chlorononan-2-one **52** following a procedure described by Hodgkinson *et al.*¹⁵⁶

The synthesis of PQS **5** described by Hodgkinson *et al.*¹⁵⁶ used a microwave reaction of 1-chlorononan-2-one **52** with anthranilic acid. It was hoped that the azide group could be installed by using 5-nitroanthranilic acid **53** in the place of anthranilic acid in this microwave reaction, so that the nitro group could then be converted to an azide group via an amine. However, the microwave-catalysed reaction failed when 5-nitroanthranilic acid **53** was used.¹⁵⁰ Therefore, a two step process was employed instead.

5-Nitroanthranilic acid **53** was heated with K₂CO₃ to deprotonate the carboxylic acid, followed by addition of 1-chlorononan-2-one **52** to form the ester **54** by S_N2 displacement of the chlorine atom in a procedure adapted from Hlaváč *et al.*¹⁵⁷ Cyclisation with polyphosphoric acid produced nitro-PQS **55** cleanly.^{157, 158}

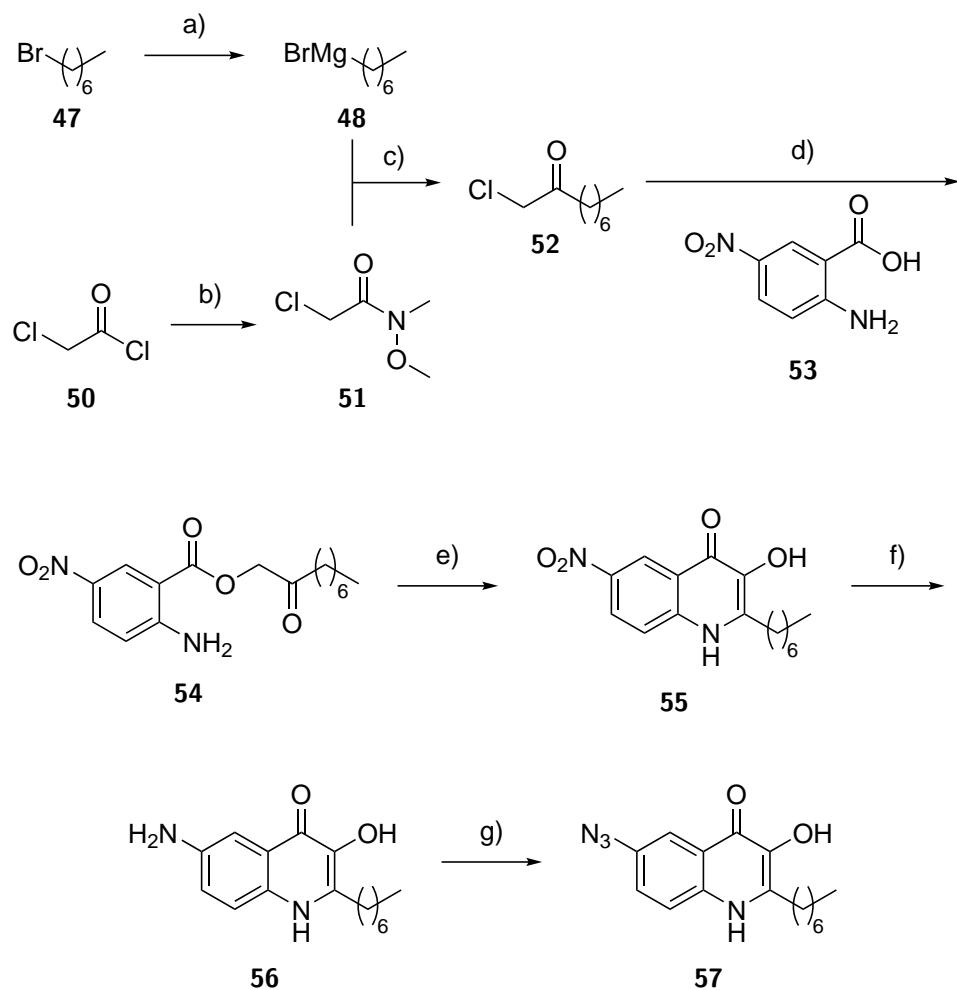
Conditions for the reduction of the nitro group were then compared (see Table 3). Baker initially used Zn and HCl, however this gave a yield over 100 % suggesting coordination of Zn to the amino-PQS **56**¹⁵⁰ (this product was taken through and purified after the next step). She also attempted reduction with Pd/C and H₂ or ammonium formate, but no reaction was observed.

Further conditions were tested in *this* work in order to obtain a clean sample of amino-PQS **56**. An initial test of reduction with SnCl₂ produced no detectable product by LCMS. Catalytic hydrogenation using harsher conditions was then attempted, and it was determined that increasing the pressure to 3 atm using a Paar hydrogenator causes full conversion in 4 h using Pd/C and H₂. Good yields (80 %) were also achieved using PtO₂ as a catalyst, with the advantage that the reaction proceeds more quickly, and at atmospheric pressure and temperature.¹⁵⁹

Finally, amino-PQS **56** was converted to azido-PQS **57** by reaction with NaNO₂ and HCl to form diazo-PQS, followed by displacement of the diazo group using NaN₃ to give the azido-PQS **57**.¹⁵⁵ The yield of this reaction was rather disappointing (28 %), and is probably due to loss of product in the supernatant following precipitation.¹⁵⁰

Conditions	Outcome
H_2 , Pd/C, 1 atm, r.t., 18 h	No reaction
NH_4HCO_2 , Pd/C, 1 atm, r.t., 18 h	No reaction
Zn, HCl (aq), r.t., 5 min	Product 56 + Zn, assumed quantitative yield
$\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$, MeOH, r.t., 18 h	No reaction
H_2 , Pd/C, MeOH, 3 atm, r.t., 4 h.	Product 56 , 100 % yield
H_2 , PtO_2 , MeOH, 1 atm, r.t., 45 min	Product 56 , 80 % yield

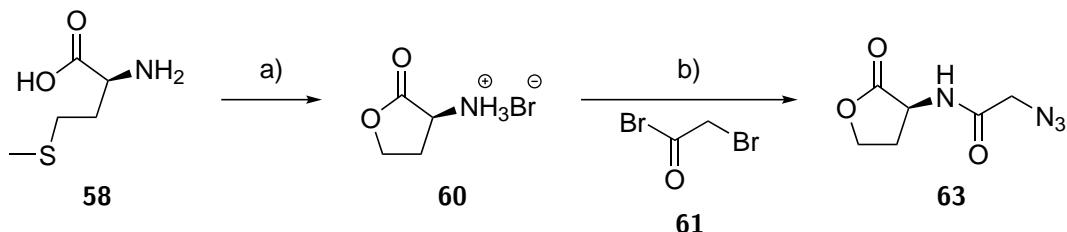
Table 3: Conditions attempted for the synthesis of **56**. Rows 1-3 were carried out by Baker,¹⁵⁰ rows 4-6 were carried out as part of this study.



Scheme 3: The synthesis of **57**. a) Mg turnings, THF, r.t., 2 h then reflux, 2 h. b) N,O -dimethylhydroxyl amine hydrochloride, K_2CO_3 , toluene, H_2O , -5°C to r.t., 30 min, 71 %. c) THF, 0°C to r.t., 15 h, 96 %. d) **53**, K_2CO_3 , DMF, 90°C , 1 h, then **52**, r.t., 18 h, 100 %. e) Polyphosphoric acid, 90°C , 5.5 h, 40 %. f) H_2 , PtO_2 , MeOH, 1 atm, r.t., 45 min, 80 %. g) i) NaNO_2 , HCl , H_2O , 0°C , 50 min. ii) NaN_3 , H_2O , r.t., 4 h, 28 % over two steps.

3.2.3 Synthesis of the azido C₄-HSL derivatives **63**, **66** and **69**

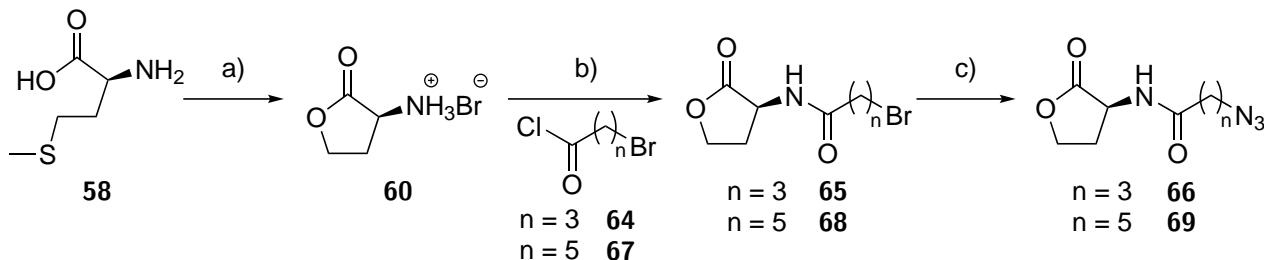
N₃-C₂-HSL **63** (the azido derivative of C₄-HSL with a C₂ chain, see Scheme 4) has previously been prepared by Stacy *et al.*¹⁶⁰ Their synthesis was followed, starting with the cyclisation of L-methionine **58** using bromoacetic acid to form the homoserine lactone HBr salt **60**. The disappointing yield can be attributed to difficulties in precipitating the final product. The homoserine lactone HBr salt **60** was then converted by a biphasic one-pot process to N₃-C₂-HSL **63** using bromoacetyl bromide **61** and NaN₃.



Scheme 4: The synthesis of **63**. a) Bromoacetic acid, *i*-PrOH:H₂O:AcOH (5:5:2), r.t., 18 h, 41 %. b) NaN₃, NaHCO₃, H₂O/CH₂Cl₂, r.t., 18 h, 41 %.

It was hoped that this procedure could also be used to produce the C₄ and C₆ derivatives, however, attempts to convert homoserine lactone **58** to N₃-C₄-HSL **66** using 4-bromobutyryl chloride **64** produced a complex mixture of products. This is likely to be because the S_N2 reaction in which the azide anion displaces bromine is slower for the C₄ derivative as the bromine atom being displaced is no longer adjacent to a carbonyl group. In addition, the longer chain length allows intramolecular cyclisation of the bromide with the secondary amide. The conversion was therefore carried out as a two-step process, where a bromoacyl chain was initially installed, followed by the S_N2 reaction with NaN₃ (see Scheme 5).

Reaction of the homoserine lactone HBr salt **60** with 4-bromobutyryl chloride **64** or 6-bromohexanoyl chloride **67** produced Br-C₄-HSL **65** or Br-C₆-HSL **68** respectively, in good yields. Heating with NaN₃ in DMF converted Br-C₆-HSL **68** to N₃-C₆-HSL **69**. Similar conditions were used by Dr. Bin Yu, a visiting PhD student in the Spring group, to convert the bromo-C₄ derivative **65** to the azido-C₄ derivative **66**, and this compound was kindly donated to complete the set. Yields for the S_N2 reaction could probably be improved by decreasing the temperature (see Scheme 14, for example).



Scheme 5: The synthesis of **66** and **69**. a) Bromoacetic acid, *i*-PrOH:H₂O:AcOH (5:5:2), r.t, 18 h, 41 %. b) NaHCO₃, H₂O/CH₂Cl₂, r.t., 18 h, **65**: 80 %, **68**: 66 %. c) NaN₃, DMF, 100 °C, 5 h, **69**: 27 % (donated by Dr. Bin Yu), **69**: 56 %.

put
intro in
intro

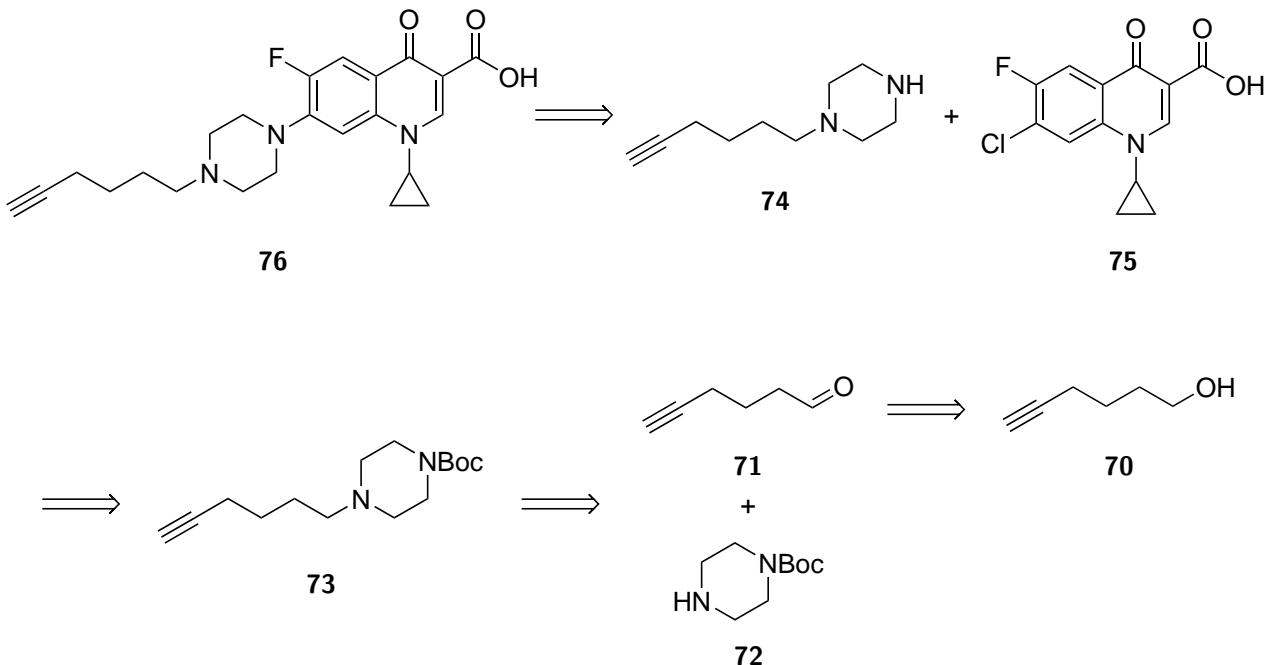
3.3 Alkynyl antibiotic derivatives

3.3.1 Synthesis of the alkynyl ciprofloxacin derivative 76

The retrosynthesis of ciprofloxacin derivative **76** is shown in Scheme 6. The disconnection to an alkynyl piperazine **76** and a commercially available ciprofloxacin precursor **75** was chosen based on a study by Renau *et al.*, who found this route to be "...superior to previous reports which involved alkylation of piperazine with an appropriate alkyl halide."^{151,161}

It was envisaged that the alkynyl piperazine **76** could be prepared from mono-Boc-protected piperazine **72** and hex-5-ynal **71** using conditions similar to those used by Renau *et al.*¹⁵¹

Unlike the aldehydes and ketones used by Renau *et al.*,¹⁵¹ hex-5-ynal **71** is not commercially available and so it was hoped that this could be prepared by oxidation of hex-5-ynol **70**.



Scheme 6: The retrosynthesis of **76**.

The synthesis of ciprofloxacin derivative **76** is shown in Scheme 7. Hex-5-ynal **71** was prepared by PCC oxidation of hex-5-ynol **70** in good yield according to the procedure described by Kocsis *et al.*¹⁶²

Renau *et al.*¹⁵¹ used sodium cyanoborohydride to facilitate the reductive amination of hex-5-ynal **71** and 1-Boc-piperazine **72**. However, it was decided to attempt this transformation using the less toxic sodium triacetoxyborohydride following a procedure reported by Abdel-Magid *et al.*¹⁶³ This reaction yielded compound **73** in excellent yield, which was deprotected using TFA using the procedure described by Renau *et al.*¹⁵¹ to give the alkynyl piperazine **74** quantitatively.

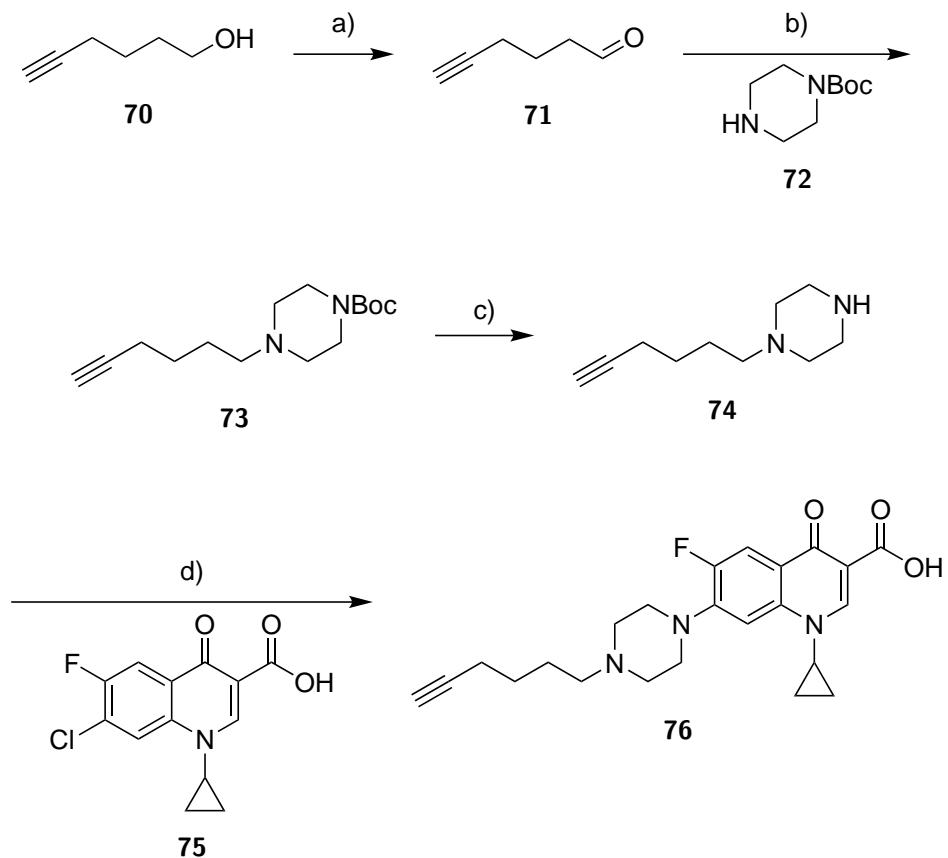
The alkynyl piperazine **74** was refluxed in MeCN with the ciprofloxacin precursor **75** according to the procedure described by Renau *et al.*,¹⁵¹ however the reaction did not proceed. Addition of 2 eq. of NEt_3 did not lead to reaction, however it was found that refluxing in neat NEt_3 led to conversion to the final ciprofloxacin derivative **76**.

With a small sample of the final product in hand, less harsh conditions were sought for a larger-scale version of the final reaction. Microwave irradiation at 115 °C was used, following a procedure by Reddy *et al.*¹⁶⁴ DMSO and NMP were tested as solvents, with or without the addition of TEA. The reactions were monitored using

LCMS, and NMP without TEA was found to give the highest conversion.

Work-up of this reaction proved difficult, with an unknown dark brown viscous liquid being formed which was difficult to separate from the white solid product. A pure sample was obtained by recrystallisation from EtOAc, but the yield was rather poor (11.8 %). The reaction was observed to stall after a certain point, while still having some of the ciprofloxacin precursor **75** present. The alkynyl piperazine **74** was not observed by TLC despite having been added in two-fold excess, suggesting that it degraded to a by-product before having chance to react.

Further attempts to refine this reaction might involve lower temperatures, higher ratios of the alkynyl piperazine **74** or improvement of the purification, e.g. by finding better precipitation conditions or by using reverse-phase chromatography. A Buchwald-Hartwig coupling or Ullmann reaction could also be attempted, but, as seen later, coordination of ciprofloxacin to Cu can hinder catalysis.



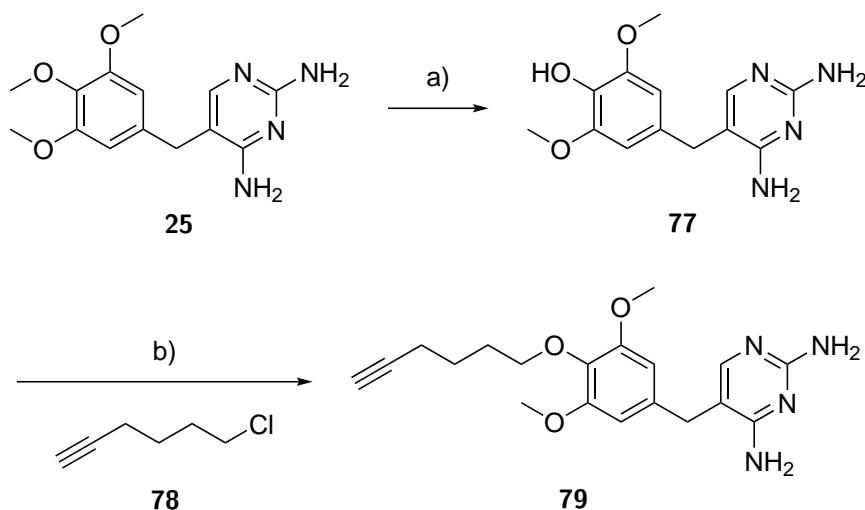
Scheme 7: The synthesis of **76**. a) Pyridinium chlorochromate, CH_2Cl_2 , r.t., 5 h, 72 %. b) $\text{NaBH}(\text{AcO})_3$, 1,2-dichloroethane, r.t., 10.5 h, 99 %. c) TFA, r.t., 1 h, 100 %. d) NMP, microwave, 115°C 24 h, 11.8 %.

3.3.2 Synthesis of the alkynyl trimethoprim derivative **79**

The synthesis of trimethoprim derivative **79** is shown in Scheme 8. Trimethoprim was selectively deprotected using HBr (aq.) using a procedure described by Jing *et al.*¹⁵² to form **77**. A slightly longer reaction time (40 min vs 20 min) probably led to the yield being slightly somewhat lower than that obtained by Jing *et al.*. The main impurity was asymmetrically di-demethylated trimethoprim, which could be identified by the presence of two aryl peaks at 6.41 (d, $J=2.0$ Hz, 1 H) and 6.34 (d, $J=2.0$ Hz, 1 H) and a corresponding methyl peak at 3.82 (s, 3 H) in the crude NMR.

The alkynyl trimethoprim derivative **79** was synthesised from the demethylated trimethoprim **77** and 6-chloro-1-hexyne **78** using a Cs_2CO_3 -catalysed $\text{S}_{\text{N}}2$ reaction similar to that used by Jing *et al.*.

weigh
Y4Tri
then
discuss



Scheme 8: The synthesis of **79**. a) HBr (aq.), 100 °C, 40 min, 43.4 %. b) Cs₂CO₃, DMF, 70 °C, 7 h, 19.6 %.

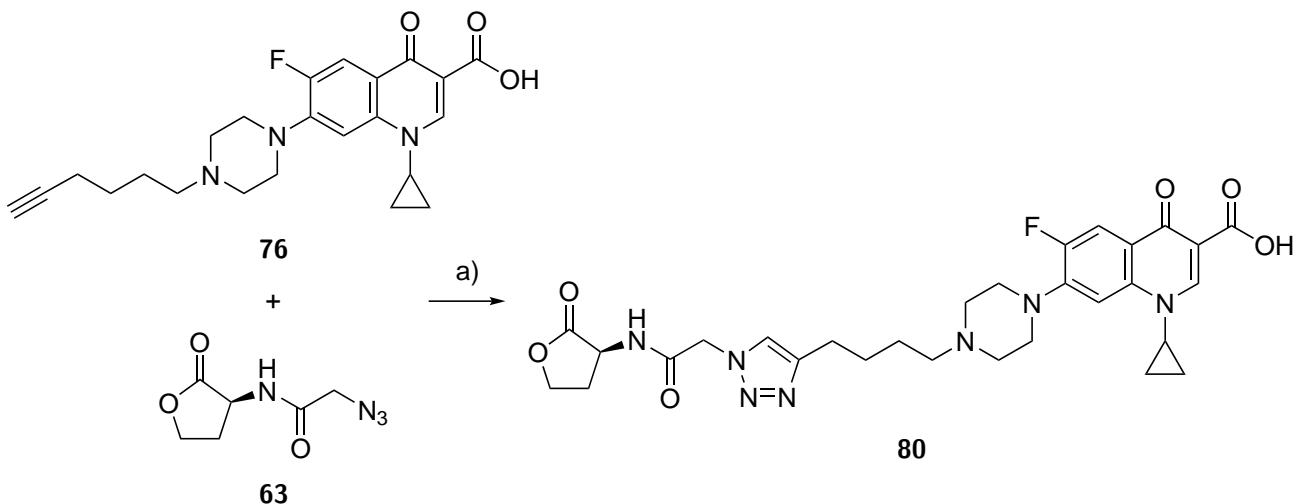
3.4 Triazole-linked autoinducer-antibiotic conjugates

3.4.1 Optimisation of the click reaction

Test reactions using N₃-C₂-HSL **63** and the alkynyl ciprofloxacin derivative **76** were performed to find conditions for the click reactions between the azido autoinducers and the alkynyl antibiotics (see Table 4 and Scheme 9). Stirring at r.t. had no effect even with an extended reaction time. Heating to 50 °C did lead to slow formation of the product, but a mixture of the 1,4 **80** and 1,5 **81** isomers was observed in an approximately 4:1 ratio by LCMS (see Figure 18). Use of the ligand tris(3-hydroxypropyltriazolylmethyl)amine (THPTA) **82** (see Figure 17) led to some conversion at room temperature, however the reaction stopped before completion, probably due to oxidation of the Cu(I) catalytic species. When degassed solvent and an argon atmosphere were used the reaction proceeded to completion at room temperature in around 3 h.

Conditions	Outcome
CuSO ₄ ·H ₂ O, sodium ascorbate, H ₂ O, <i>t</i> -BuOH, air, r.t., 7 d.	No reaction
CuSO ₄ ·H ₂ O, sodium ascorbate, H ₂ O, <i>t</i> -BuOH, air, 50 °C, 5 d.	1,3-Triazole product 80 and 1,5 triazole impurity 81 4:1
CuSO ₄ ·H ₂ O, sodium ascorbate, THPTA 82 , H ₂ O, <i>t</i> -BuOH, air, r.t., 3 h.	1,3-Triazole product 80 and starting materials 63 and 76
CuSO ₄ ·H ₂ O, sodium ascorbate, THPTA 82 , H ₂ O, <i>t</i> -BuOH, Ar, r.t., 3 h.	1,3-Triazole product 80

Table 4: Conditions attempted for the synthesis of **80** (see Scheme 9).



Scheme 9: Synthesis of **80**. For conditions see Table 4.

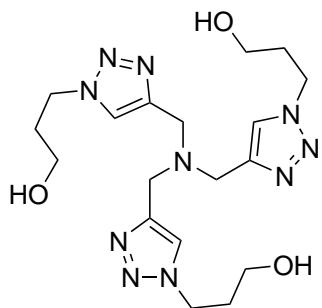


Figure 17: Tris[(1-benzyl-1*H*-1,2,3-triazol-4-yl)methyl]amine (THPTA) **82**.

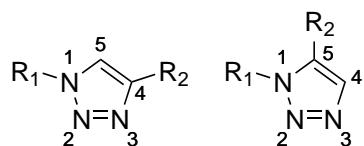
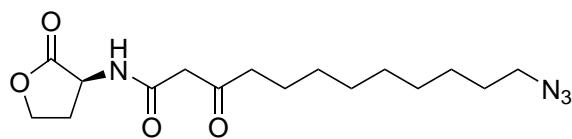


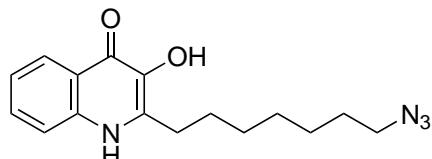
Figure 18: 1,4 (left) and 1,5 (right) triazoles.

3.4.2 Synthesis of the autoinducer-ciprofloxacin and autoinducer-trimethoprim triazole conjugates

Once conditions had been found for the click reaction, the synthesis of other conjugates was attempted. Two additional azides were kindly donated by members of the Spring group: the azido derivative of 3-oxo-C₁₂-HSL **83** was synthesised by Ryan Howard, a master's student under my supervision¹⁶⁵ and the tail azide derivative of PQS **84** was synthesised by Ysobel Baker¹⁵⁰ (see Figure 19).



83



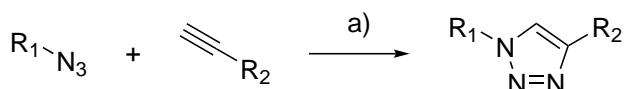
84

Figure 19: Further azido autoinducer derivatives synthesised by Howard¹⁶⁵ **83** and Baker¹⁵⁰ **84**.

Synthesis of the conjugates proved more difficult than expected, for several reasons. Firstly some compounds did not dissolve in the reaction solvent (50 % water/*t*-BuOH) requiring addition of co-solvents such as CH₂Cl₂. Secondly, some compounds were unstable: HSL derivatives hydrolysed upon attempted preparative HPLC purification and the 3-oxo-C₁₂-HSL conjugates degraded during the reaction. Finally, the reaction was highly air-sensitive which led to stalling. The most reliable procedure was determined over the course of several reactions, and is shown in 5.25.

Nonetheless, several conjugates were produced for testing. The results of the reactions are shown in Table 5, Table 6, Table 7 and Table 8. It was intended that the failed reactions would be repeated, but as preliminary biological testing proved unpromising it was decided that attention should be focused elsewhere.

ref



Scheme 10: General scheme for the click reaction, where R₁-N₃ is an azido autoinducer derivative and R₂-≡ is an alkynyl antibiotic derivative a)CuSO₄, sodium ascorbate, THPTA, H₂O, *t*-BuOH.

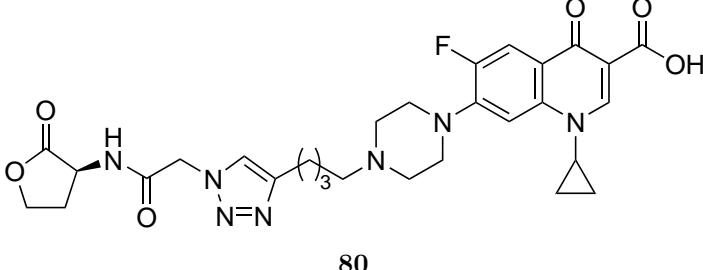
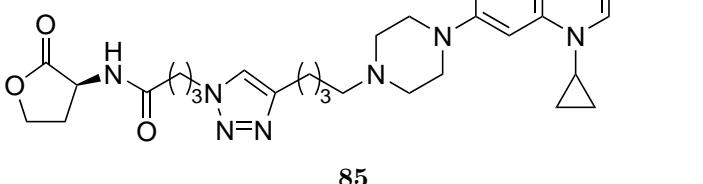
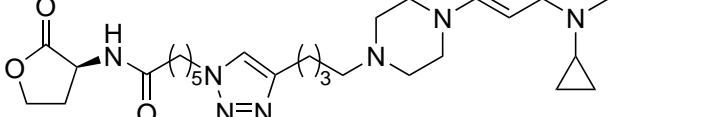
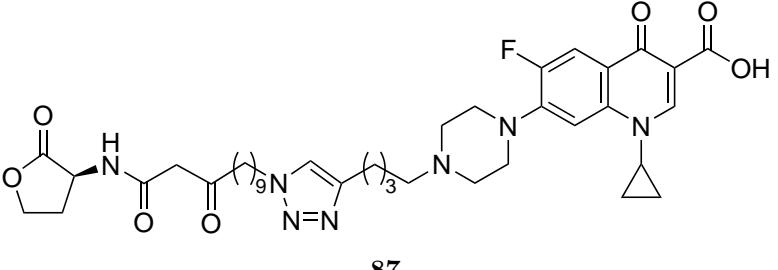
Starting materials	Product	Outcome	Yield
63 and 76		✓ Reaction complete by LCMS in 3 h. Purified by column chromatography (SiO ₂ , 0 - 20 % MeOH/CH ₂ Cl ₂). 29.6 %	
66 and 76		✓ Reaction complete by LCMS in 3 h. Purified by column chromatography (SiO ₂ , 0 - 20 % MeOH/CH ₂ Cl ₂). 46.8 %	
69 and 76		✓ Reaction complete by LCMS in 3 h. Purified by column chromatography (SiO ₂ , 0 - 20 % MeOH/CH ₂ Cl ₂). 38.0 %	
83 and 76		✗ Reaction complete by LCMS in 3.5 h, but product degraded when subjected to column chromatography (SiO ₂ , 20 % MeOH/CH ₂ Cl ₂). -	

Table 5: Click reactions attempted.

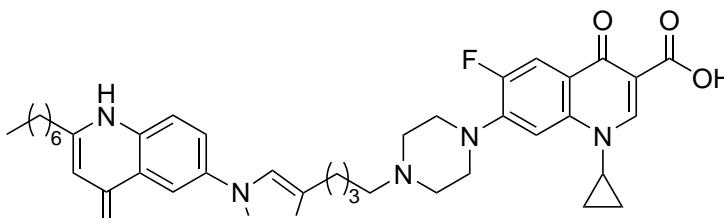
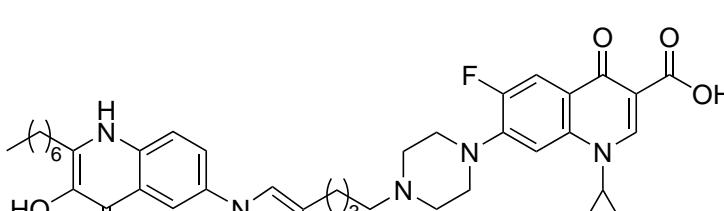
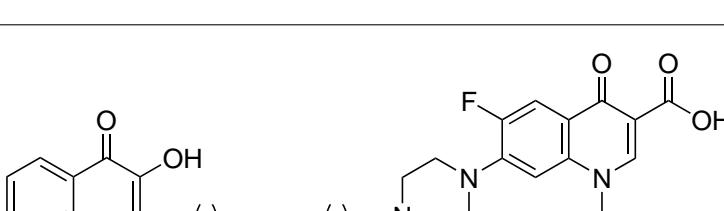
Starting materials	Product	Outcome	Yield
46 and 76	 <p style="text-align: center;">88</p>	✓ Reaction complete by LCMS in 1.5 h. Purified by prep. HPLC.	27.0 %
57 and 76	 <p style="text-align: center;">89</p>	✗ Reaction did not go to completion by LCMS. Attempted purification by prep. HPLC but unsuccessful.	
84 and 76	 <p style="text-align: center;">90</p>	✗ No reaction seen by LCMS.	

Table 6: Click reactions attempted.

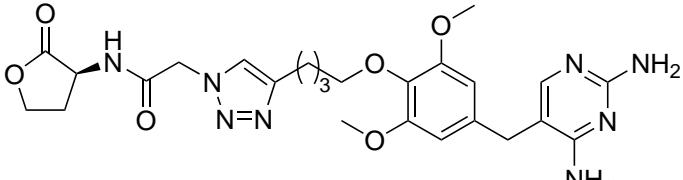
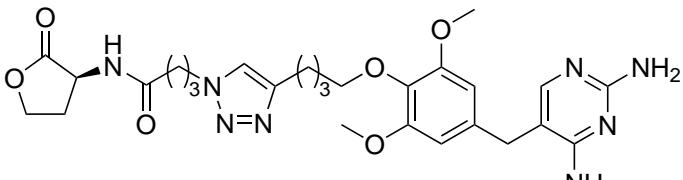
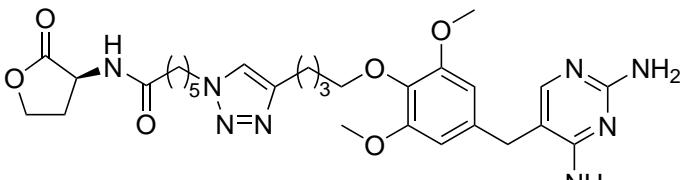
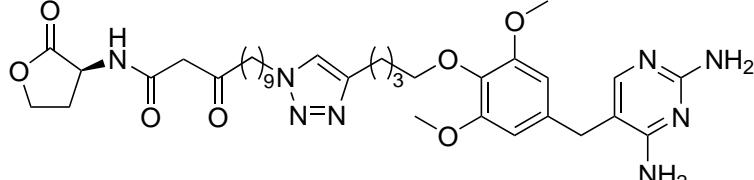
Starting materials	Product	Outcome	Yield
63 and 79	 91	✗ Reaction complete by LCMS in 2 h, but lactone hydrolysed on prep. HPLC column.	
66 and 79	 92	✓ Reaction complete by LCMS in 2 weeks (stalled). Purified by column chromatography (SiO2, 20 % MeOH/CH2Cl2).	16.8 %
69 and 79	 93	✓ Reaction complete by LCMS in 2 weeks (stalled). Purified by column chromatography (SiO2, 20 % MeOH/CH2Cl2).	26.8 %
83 and 79	 94	✗ Degraded during reaction.	

Table 7: Click reactions attempted.

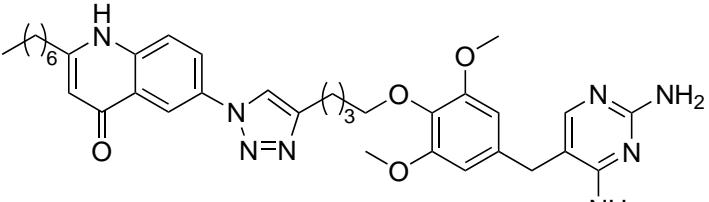
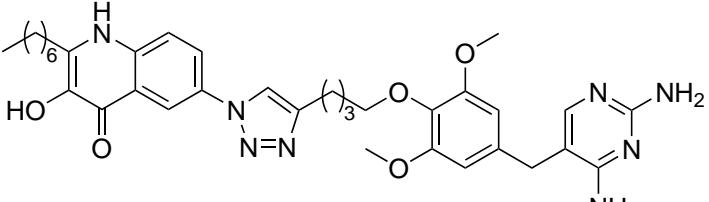
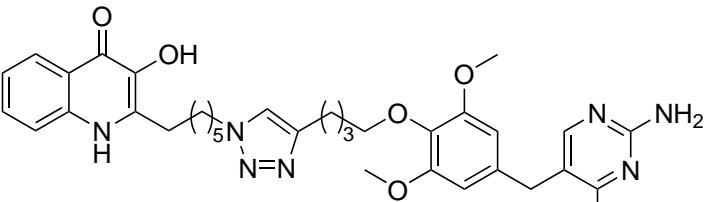
Starting materials	Product	Outcome	Yield
46 and 79	 95	✓ Reaction complete by LCMS in 1.5 h. Purified by prep. HPLC.	41.0 %
57 and 79	 96	✗ Reaction did not go to completion by LCMS. Attempted purification by prep. HPLC but unsuccessful.	
84 and 79	 97	✓ Reaction complete by LCMS in 3 h. Purified by column chromatography (SiO2, 20 % MeOH/CH2Cl2).	18.3 %

Table 8: Click reactions attempted.

3.4.3 Synthesis of homoserine lactone-ciprofloxacin triazole conjugates with cleavable linkers

In addition to the conjugates shown in the previous section, a further collection was synthesised in collaboration with Prof. Eddy Sotelo, a visiting researcher in the Spring group. Prof. Sotelo synthesised two alkyne-linked ciprofloxacin derivatives **98** and **99** (see Figure 20), both with cleavable linkers (see ??).

link
this up

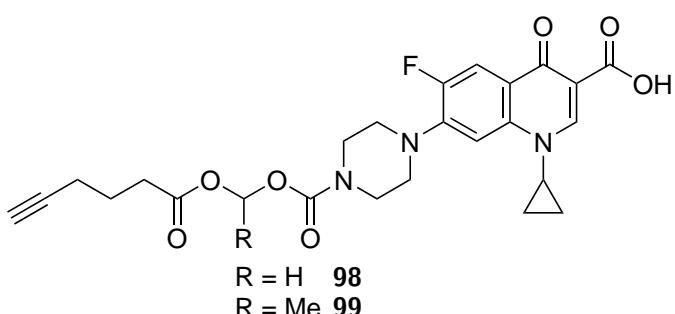


Figure 20: The cleavable alkyne-Cip derivatives synthesised by Prof. Sotelo.

Prof. Sotelo then performed click reactions using the AHL azide derivatives **63**, **66** and **69** shown in 3.2.3 to form a library of conjugates (see Figure 21). It was hoped that these conjugates would enter the cell and then be cleaved by esterases to release ciprofloxacin (see ??).

link
this up
should
I show
the
syn-
thesis?

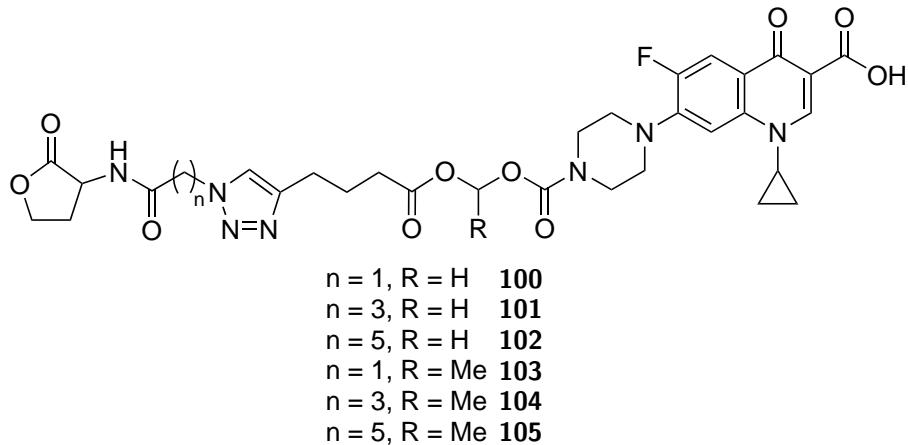


Figure 21: The cleavable HSL-Cip triazole conjugates synthesised by Prof. Sotelo.

In addition, two control compounds **106** and **107** with benzyl head groups were produced by Prof. Sotelo (see Figure 22). It was hoped that these would show whether the AHL head group is required for activity.

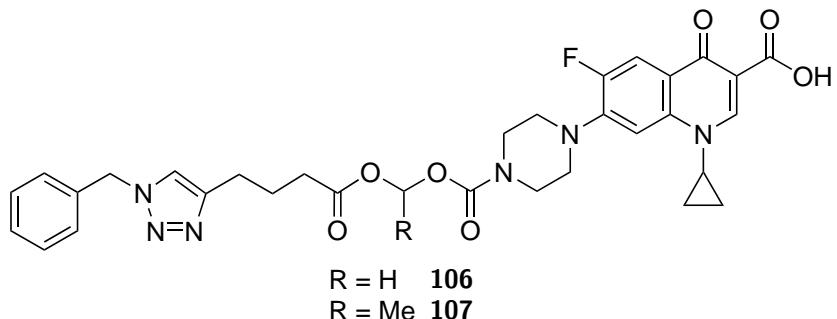


Figure 22: The cleavable Bn-Cip triazole conjugates **106** and **107** synthesised by Prof. Sotelo.

4 Autoinducer analogue-ciprofloxacin conjugates

4.1 Introduction

4.1.1 Head groups

The head groups used in this study are shown in Figure 23. The cyclohexanol derivatives were synthesised as a diastereomerically pure racemate, whereas the cyclopentanol derivatives were synthesised as separate enantiomers. Unfortunately, cyclopentanone derivatives were not synthesised, and would be an obvious future addition to the library. The 2-methoxybenzene derivatives do not have precedents as quorum sensing modulators in the literature, but they were included so as to be compared with the 3-methoxybenzene derivatives.

check
Bour-
sier2018
for
print
publica-
tion
details

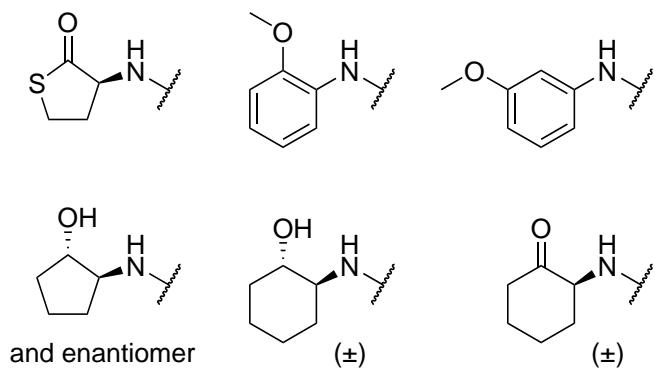
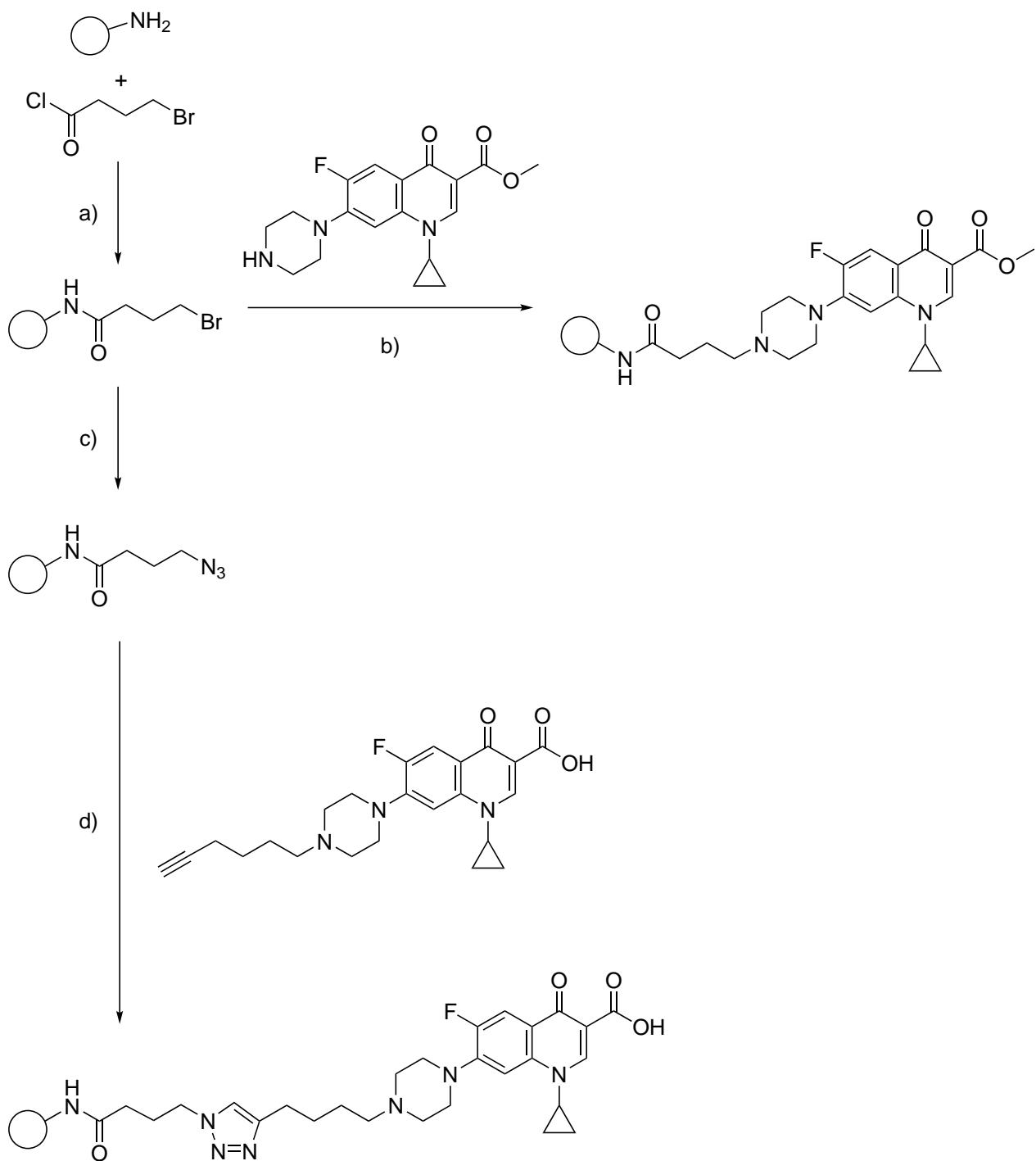


Figure 23: The head groups used in this section.

4.1.2 Library construction

As Ganguly *et al.*⁷ synthesised their conjugate from Br-C₄-HCTL, it was envisaged that a branching strategy could be used to produce two sets of conjugates (see Scheme 11). The first set would be formed by the S_N2 reaction of the relevant bromide with methyl ciprofloxacin. The second set would be made by displacing the bromide with azide, then performing a click reaction with the alkynyl ciprofloxacin derivative **76** made previously to form the triazole-linked product. Ketone conjugates would be formed by oxidation of the alcohols.

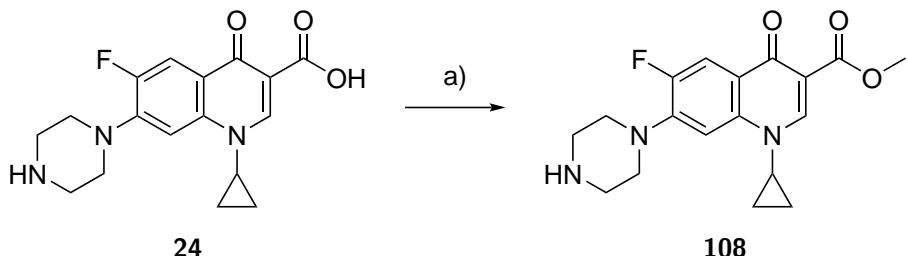


Scheme 11

4.2 Homocysteine thiolactone derivatives

4.2.1 Synthesis of methyl ciprofloxacin 108

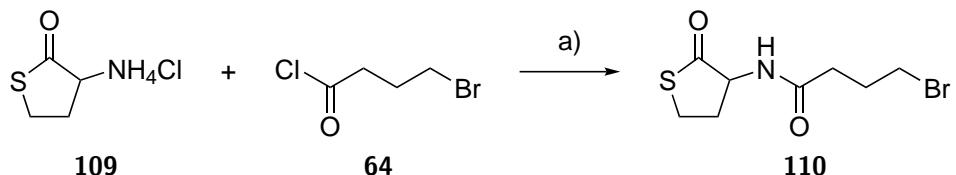
The synthesis of the analogue conjugates began with the synthesis of methyl ciprofloxacin **108**, which would then be attached to the various head groups. Methyl ciprofloxacin **108** was synthesised from ciprofloxacin **24** and MeOH in very good yield using *para*-toluenesulfonic acid as a catalyst.¹⁶⁶



Scheme 12: Synthesis of methyl ciprofloxacin **108**. a) *p*-TSA, MeOH, 72 h, reflux, 83.3 %.

4.2.2 Synthesis of Br-C₄-HCTL **110**

The HCTL head group was then attached to the linker to form Br-C₄-HCTL **110**, in preparation for coupling to methyl ciprofloxacin **108**. Br-C₄-HCTL **110** was synthesised using the Schotten-Baumann conditions employed previously for the HSL derivatives **65** and **68**. Br-C₄-HCTL **110** was isolated in markedly higher yield than that achieved by Ganguly *et al.*¹³⁴ (87.9 % vs. 25.0 %). It is possible that this was due to CH₂Cl₂ being used for the extraction, whereas Ganguly *et al.* used EtOAc.

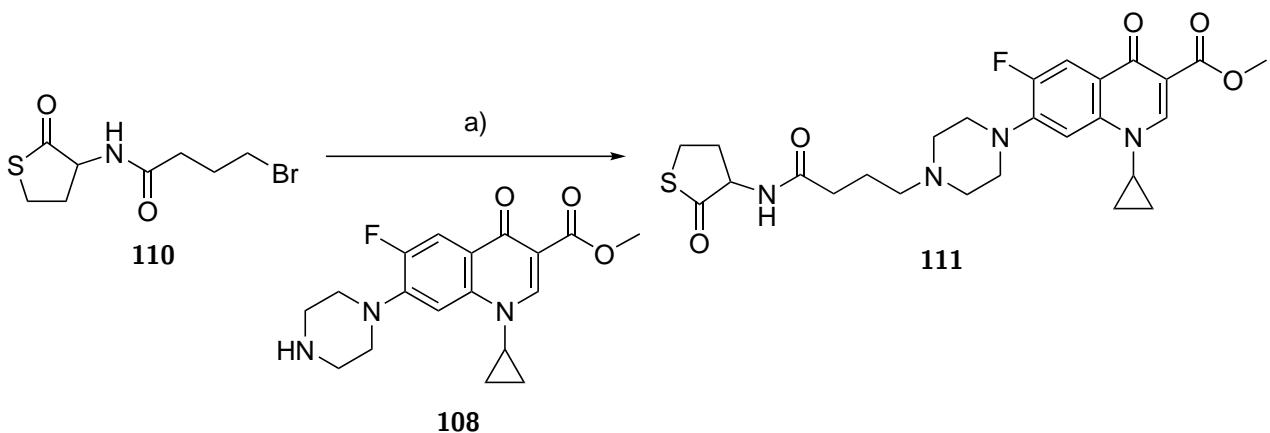


Scheme 13: Synthesis of Br-C₄-HCTL **110**. a) NaHCO₃, CH₂Cl₂, H₂O, 0 °C, 1 h, 87.9 %.

4.2.3 Synthesis of the HCTL-CipMe conjugate **111**

The HCTL-CipMe conjugate **111** was synthesised using the procedure outlined by Ganguly *et al.*¹³⁴ Monitoring by LCMS showed slow conversion to the product. Br-C₄-HCTL **110** was presumably consumed by side reactions as 4 eq. were required to reach full conversion. Ganguly *et al.* do not quote a yield for comparison,^{134,135} but it is hoped that the 12.2 % achieved here could be improved upon. The side reactions led to the production of an unidentified brown, viscous contaminant which made purification by flash column chromatography (as was used by Ganguly *et al.*) challenging. Preparatory HPLC on a partially purified sample gave enough pure HCTL-CipMe conjugate **111** for biological testing.

Future optimisation of the synthesis could focus on different routes to the product, e.g. the peptide coupling described in 4.5.4, or different purification methods, e.g. using just preparatory HPLC, or reverse phase flash column chromatography.

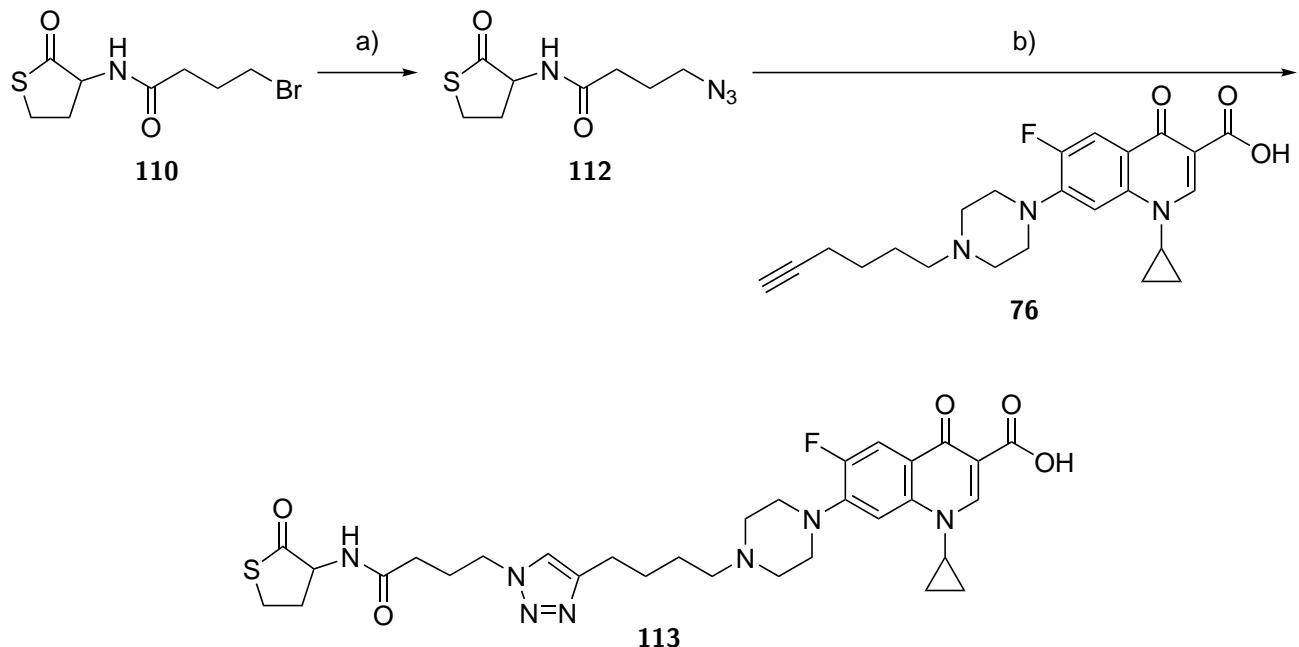


Scheme 14: Synthesis of the HCTL-CipMe conjugate **111**, $\text{N}_3\text{-C}_4\text{-HCTL}$ **112**, and the HCTL-Cip triazole conjugate **113**. a) K_2CO_3 , acetonitrile, reflux, 24 h, 12.2 %.

4.2.4 Synthesis of the HCTL-Cip triazole conjugate **113**

$\text{Br-C}_4\text{-HCTL}$ **110** was converted into $\text{N}_3\text{-C}_4\text{-HCTL}$ **112** (see Scheme 14), by an $\text{S}_{\text{N}}2$ reaction with sodium azide which proceeded in excellent yield.

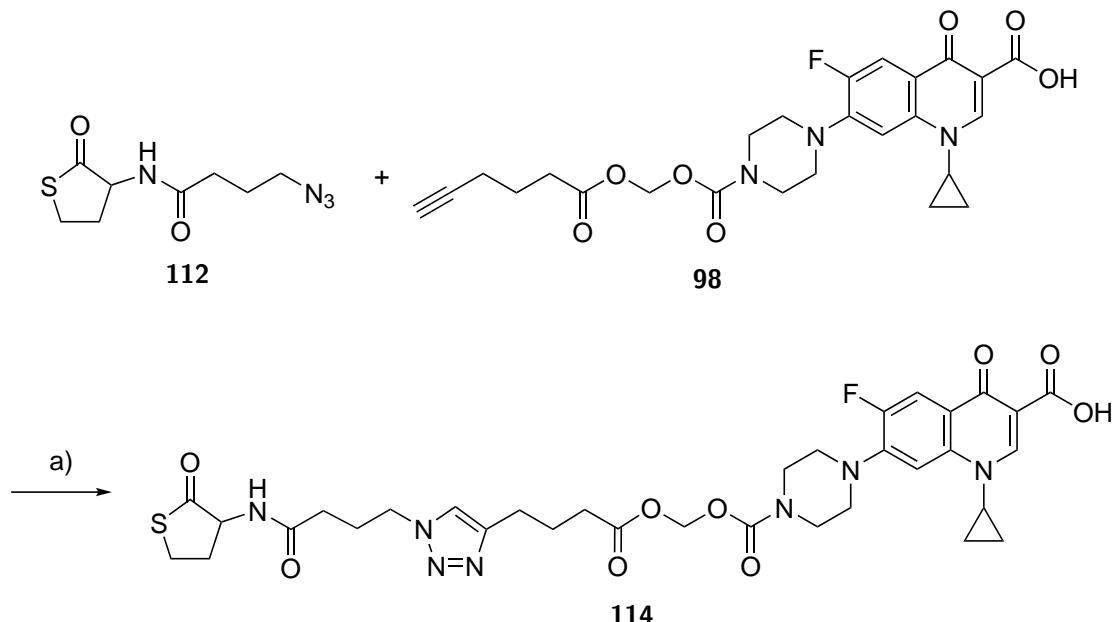
$\text{N}_3\text{-C}_4\text{-HCTL}$ **112** was then subjected to the click reaction conditions optimised previously (see 5.25). The reaction proceeded very slowly at first, until it was realised that the azide did not dissolve in the reaction solvent and formed a single solid clump. DMSO was added as a co-solvent, and the reaction began to proceed, albeit still slowly. It is possible that the sulfur atom coordinates to the copper, thus inhibiting its catalytic ability. Nonetheless the HCTL-Cip triazole conjugate **113** was eventually isolated in good yield (see Scheme 15).



Scheme 15: Synthesis of the HCTL-Cip triazole conjugate **113**. a) NaN_3 , acetonitrile, reflux, 1.5 h, 89.3 %. b) CuSO_4 , THPTA, sodium ascorbate, H_2O , $t\text{-BuOH}$, DMSO, r.t., 7 d, 70.6 %.

4.2.5 Synthesis of the cleavable HCTL-Cip triazole conjugate 114

A cleavable conjugate **114** was also synthesised from $\text{N}_3\text{-C}_4\text{-HCTL}$ **112** by reaction with a cleavable alkyne-Cip derivative **98** synthesised previously by Prof. Eddy Sotelo-Perez (see 3.4.3). Conditions developed by Prof. Sotelo-Perez were used, but again the reaction proceeded very slowly. The disappointing yield is, however, most likely due to losses during purification.

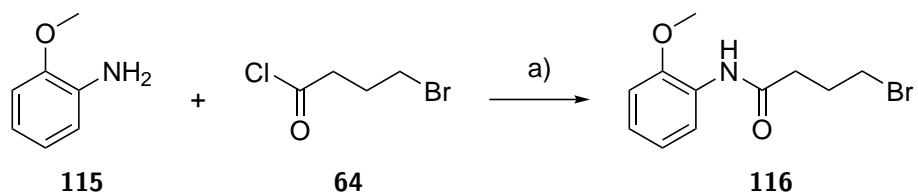


Scheme 16: Synthesis of the cleavable HCTL-Cip triazole conjugate **114**. a) CuI , DIPEA, CH_2Cl_2 , r.t., 3 h, 5.0 %.

4.3 2-Methoxybenzene derivatives

4.3.1 Synthesis of Br-C₄-2-methoxybenzene **116**

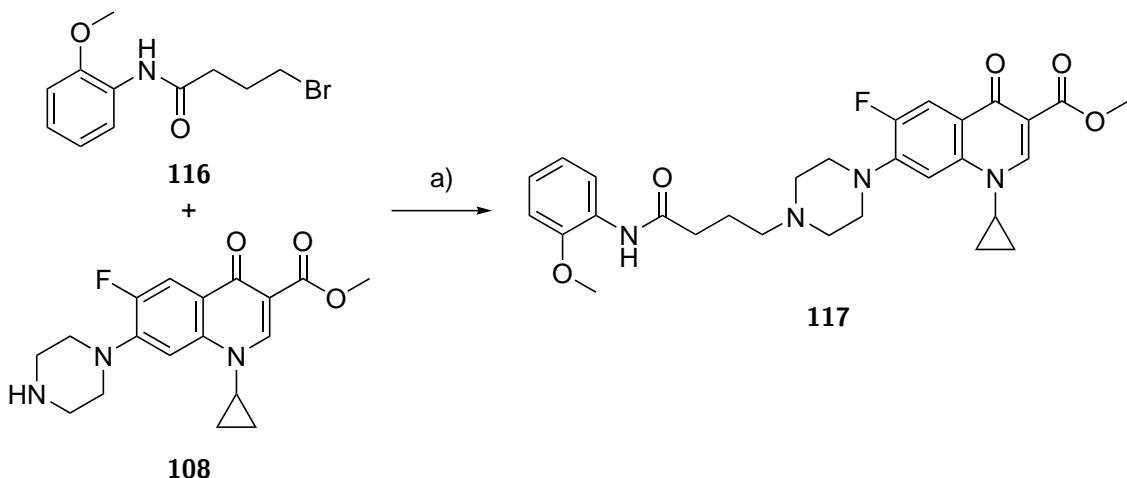
Br-C₄-2-methoxybenzene **116** was synthesised from 2-methoxyaniline **115** and 4-bromobutyryl chloride **64** using Schotten-Baumann conditions in 50.0 % yield (see Scheme 17). The compound is air and/or light sensitive, turning from an initially colourless liquid to blue then black if left out on the bench. It is likely that the mediocre yield is due to degradation during columning, and it is suggested that in future the compound should be used in its crude form to minimise exposure to air and light, as it was fairly pure by ¹H NMR before columning.



Scheme 17: Synthesis of Br-C₄-2-methoxybenzene **116**. a) NaHCO_3 , CH_2Cl_2 , H_2O , 0 °C, 1 h, 50.0 %.

4.3.2 Synthesis of the 2-methoxybenzene-CipMe conjugate **117**

The procedure outlined by Ganguly *et al.*¹³⁴ was initially attempted in order to synthesise the 2-methoxybenzene-CipMe conjugate **117**, but the reaction was very slow and did not go to completion, presumably due to degradation of Br-C₄-2-methoxybenzene **116**. New conditions, employing a microwave reactor and 2 eq. of Br-C₄-2-methoxybenzene **116** were then attempted, with a much greater conversion observed by LCMS after 4 h (see Scheme 18). However, a poor yield was obtained, potentially due to degradation during column chromatography, which took longer than for Br-C₄-2-methoxybenzene **116** because the 2-methoxybenzene-CipMe conjugate **117** is more polar.



Scheme 18: Synthesis of the 2-methoxybenzene-CipMe conjugate **117** and N₃-C₄-2-methoxybenzene **118**. a) NaI, DIPEA, acetonitrile, microwave reactor, 100 °C, 4 h, 10.2 %.

4.3.3 Synthesis of the 2-methoxybenzene-Cip triazole conjugate **119**

N₃-C₄-2-methoxybenzene **118** was synthesised from Br-C₄-2-methoxybenzene **116** by an S_N2 reaction with sodium azide (see ??). The yield of N₃-C₄-2-methoxybenzene **118** (26.7 %) was a lot lower than for N₃-C₄-HCTL **112** (89.3 %). The colour of N₃-C₄-2-methoxybenzene **118**, like its precursor, changed from clear to blue then black, suggesting that it is also air/light sensitive and may have degraded during columning. However, in this case it may not be better to use this product crude as several impurities could be observed by LCMS (see Figure 24).

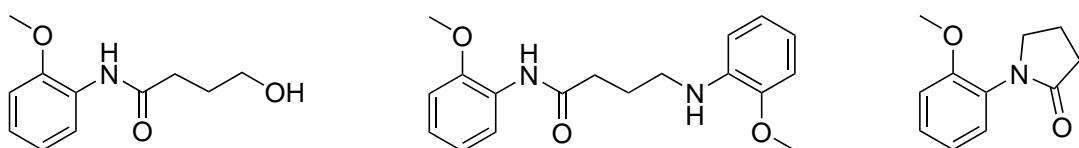
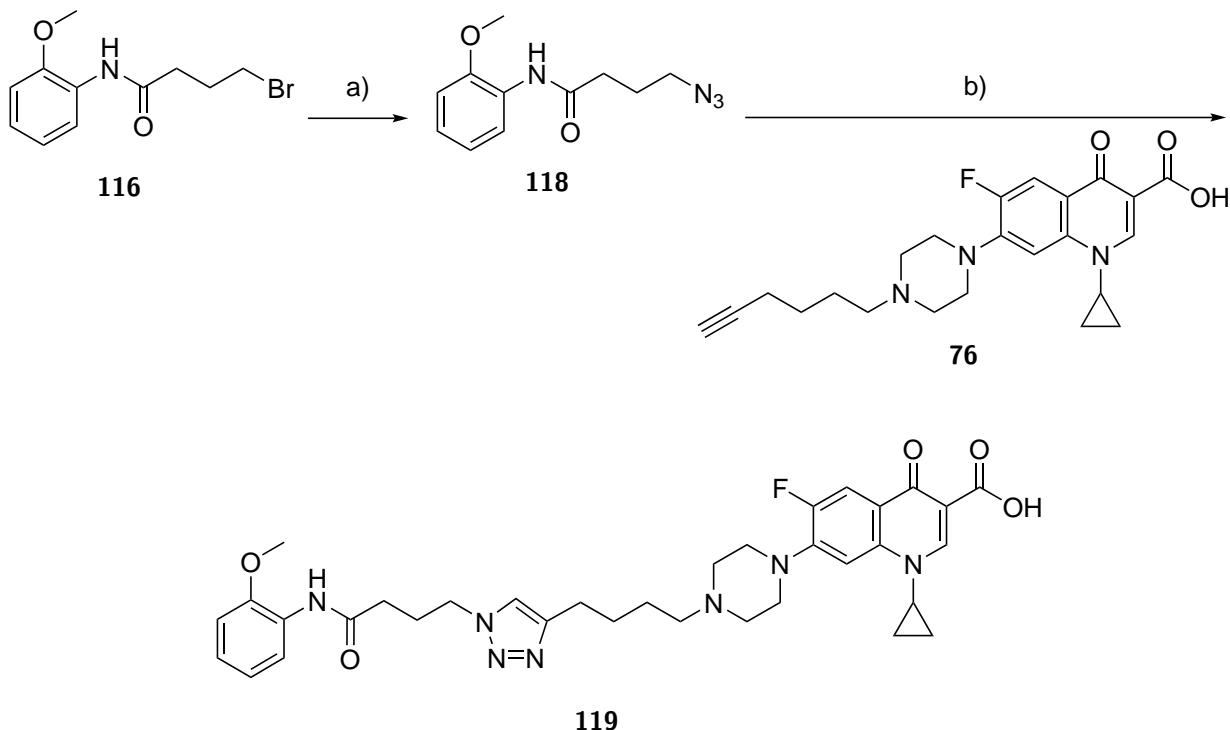


Figure 24: Impurities formed during the synthesis of N₃-C₄-2-methoxybenzene **118**.

The 2-methoxybenzene-Cip triazole conjugate **119** was synthesised using the standard click conditions (see 5.25), with the addition of CH₂Cl₂ as a co-solvent to aid the dissolution of N₃-C₄-2-methoxybenzene **118** (see Scheme 19). Again, the yield was somewhat low, probably due to air/light sensitivity of the starting material and/or product.

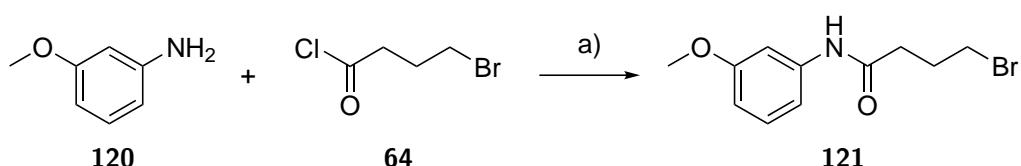


Scheme 19: Synthesis of the 2-methoxybenzene-Cip triazole conjugate **119**. a) NaN_3 , acetonitrile, reflux, 2 h, 26.7 %. b) CuSO_4 , THPTA, sodium ascorbate, H_2O , *t*-BuOH, CH_2Cl_2 , r.t., 16 h, 39.0 %.

4.4 3-Methoxybenzene derivatives

4.4.1 Synthesis of Br-C₆-3-methoxybenzene 121

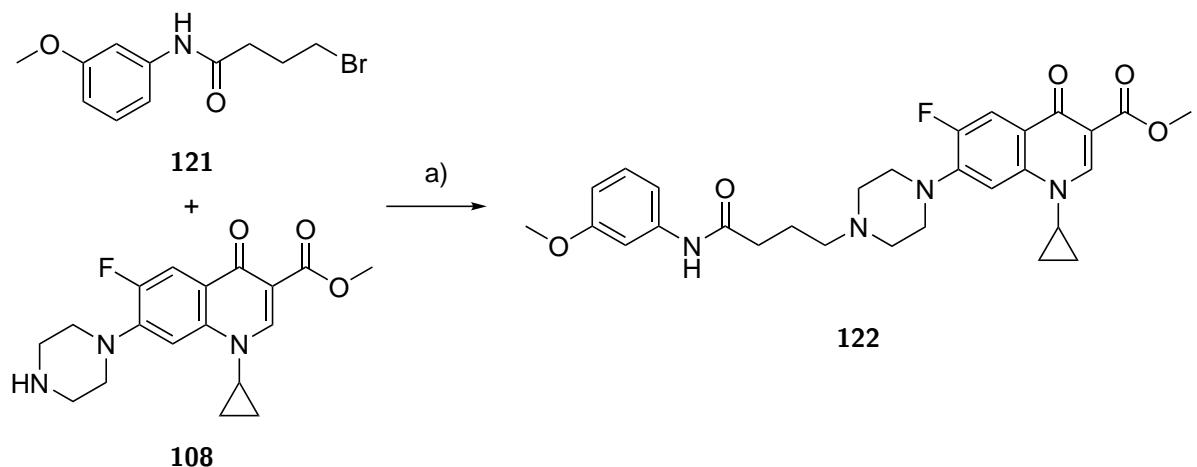
Br-C₄-3-methoxybenzene **121** was synthesised from 3-methoxyaniline **120** and 4-bromobutyryl chloride **64** using Schotten-Baumann conditions as above in almost identical (49.6 %) yield (see Scheme 20). The compound is probably also air and/or light sensitive, turning from a pale pink amorphous solid to a pale brown liquid.



Scheme 20: Synthesis of Br-C₄-3-methoxybenzene **116**. a) NaHCO₃, CH₂Cl₂, H₂O, 0 °C, 1 h, 49.6 %.

4.4.2 Synthesis of the 3-methoxybenzene-CipMe conjugate 122

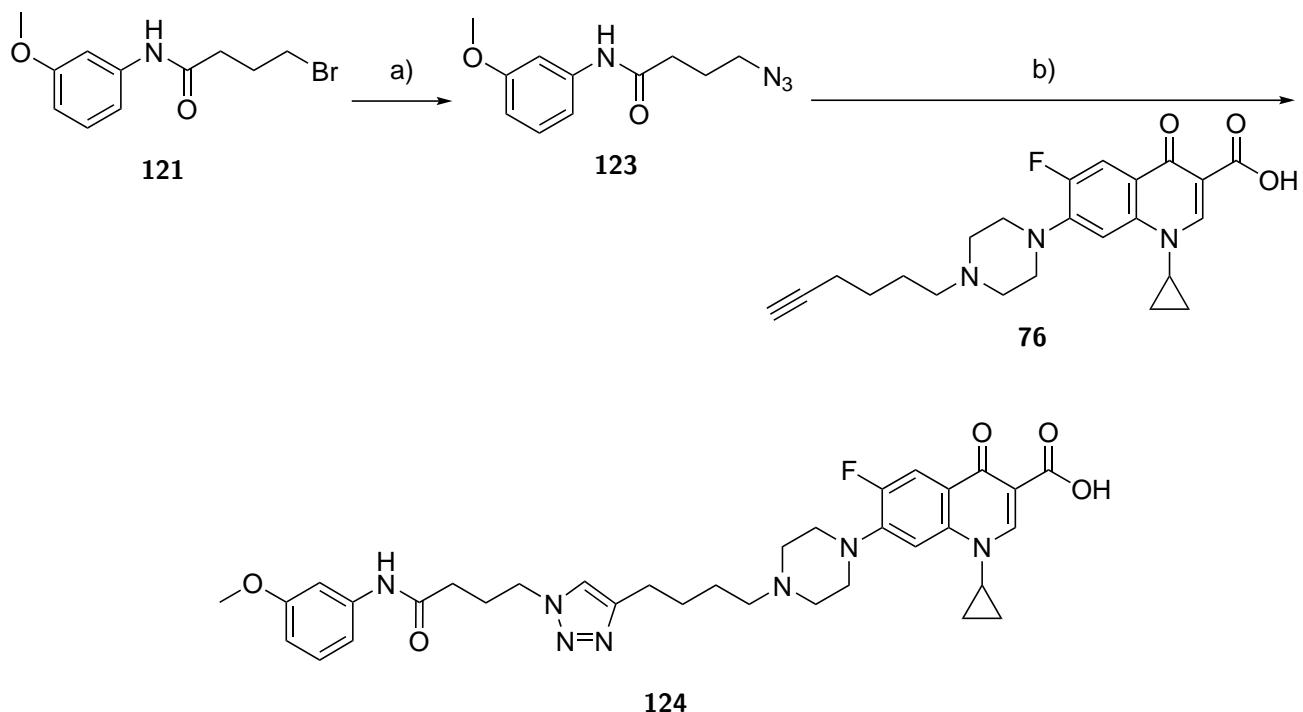
The 3-methoxybenzene-CipMe conjugate **122**, was synthesised as above, in similar yield (see Scheme 21).



Scheme 21: Synthesis of the 3-methoxybenzene-CipMe conjugate **122** and N₃-C₄-3-methoxybenzene **123**. a) NaI, DIPEA, acetonitrile, microwave reactor, 100 °C, 4 h, 10.5 %.

4.4.3 Synthesis of the 3-methoxybenzene-Cip triazole conjugate **124**

N₃-C₄-2-methoxybenzene **118** and the 3-methoxybenzene-Cip triazole conjugate **124** were synthesised as above, in similar yields (see Scheme 21 and Scheme 22).

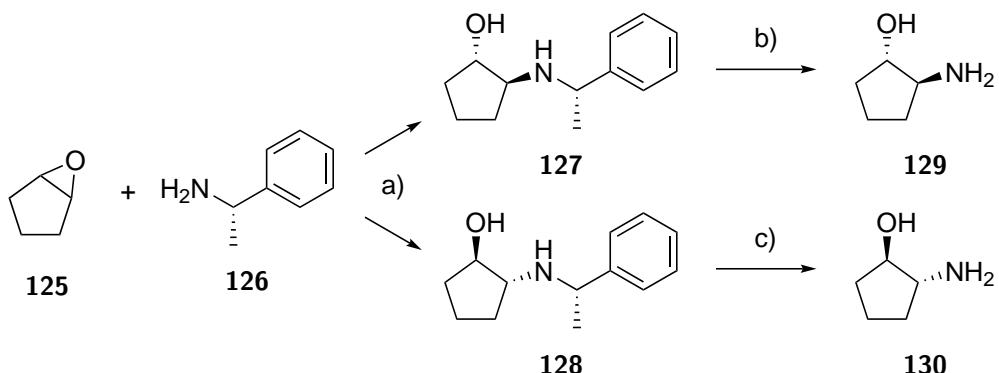


Scheme 22: Synthesis of the 3-methoxybenzene-Cip triazole conjugate **124**. a) NaN₃, acetonitrile, reflux, 7 h, 16.7 %. b) CuSO₄, THPTA, sodium ascorbate, H₂O, *t*-BuOH, CH₂Cl₂, r.t., 2 h, 5.0 %.

4.5 Cyclopentanol derivatives

4.5.1 Synthesis of the 2-aminocyclopentan-1-ol head groups **129** and **130**

Synthesis of the cyclopentanol derivatives began with the synthesis of $(1S,2S)$ -2-aminocyclopentan-1-ol **129** and $(1R,2R)$ -2-aminocyclopentan-1-ol **130** (see Scheme 23), using a procedure reported by Overman and Sugai.^{167–169} These precursors were synthesised by opening cyclopentene oxide **125** using (S) -1-phenylethanimine **126** to give approximately equal amounts of two diastereomers, **127** and **128**, which were separated using column chromatography. The removal of the methylbenzyl groups proved more difficult than expected, with the conditions reported by Overman and Sugai¹⁶⁸ yielding only a salt of the starting material. After several attempts under various conditions (including using the free amine vs. the salt, varying the temperature, ensuring the dryness of the reagents and adding acetic acid), an approach using H_2 gas was attempted (see Table 9). This proceeded smoothly at 5 atm to give the two enantiomers of 2-aminocyclopentan-1-ol, **129** and **130**, both in quantitative yield.



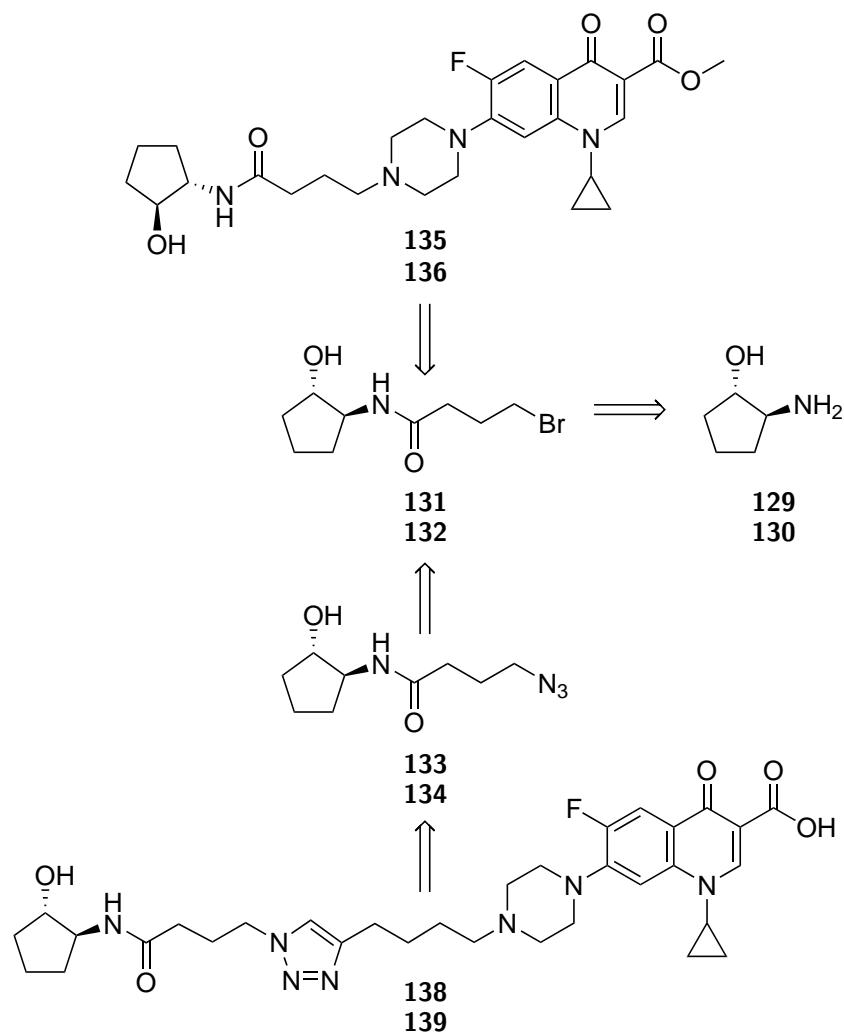
Scheme 23: Synthesis of $(1S,2S)$ -2-aminocyclopentan-1-ol **129** and $(1R,2R)$ -2-aminocyclopentan-1-ol **130**. a) $AlMe_3$, CH_2Cl_2 , $0\text{ }^\circ C$, **127** (*SSS*): 35.2 %, **128** (*RRS*): 32.1 %. b) See Table 9. c) $Pd(OH)_2$, $MeOH$, H_2 , 5 atm, r.t., 1 d, 100 %.

Conditions	Temperature and pressure	Time	Result
127 · HCl, ammonium formate, 10 % Pd/C, DMF	r.t., 1 atm	2 d	127 salt
127 , ammonium formate, 10 % Pd/C, DMF	r.t., 1 atm	2 d	127 salt
127 · HCl, ammonium formate, 10 % Pd/C, dry DMF	r.t., 1 atm	2 d	127 salt
128 , ammonium formate, 10 % Pd/C, dry DMF	r.t., 1 atm	2 d	128 salt
127 , ammonium formate, 10 % Pd/C, dry DMF	70 °C, 1 atm	1 d	127 salt
127 , ammonium formate, 10 % Pd/C, dry DMF, AcOH	70 °C, 1 atm	1 d	Complex mixture
127 · HCl, dry ammonium formate, 10 % Pd/C, dry DMF	120 °C, 1 atm	7 d	Complex mixture
127 · HCl, Pd(OH) ₂ , MeOH, H ₂	r.t., 1 atm	1 d	127 salt
127 · HCl, Pd(OH) ₂ , MeOH, H ₂	r.t., 3.4 atm	1 d	129 salt, 127 salt, and an unidentified compound (approx. 7:2:10 by ¹ H NMR)
127 , Pd(OH) ₂ , MeOH, H ₂	r.t., 5 atm	1 d	129 , 100 % yield

Table 9: Conditions attempted for the synthesis of (*1S,2S*)-2-aminocyclopentan-1-ol **129** and (*1R,2R*)-2-aminocyclopentan-1-ol **130** (see Scheme 23).

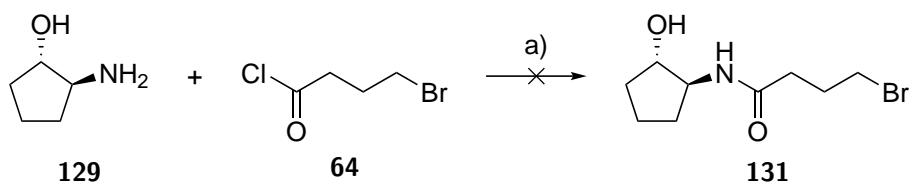
4.5.2 Initial branching route

An initial retrosynthesis of the conjugates is shown in Scheme 24, and follows a similar path to previous conjugates.



Scheme 24: Retrosynthetic of the cyclopentanol-CipMe conjugates **135** (*SS*) and **136** (*RR*), and the cyclopentanol-Cip triazole conjugates **138** (*SS*) and **139** (*RR*). *SS* enantiomers are shown, but both are implied.

Synthesis of Br-C₄-cyclopentanol-(*SS*) **131** from (1*S*,2*S*)-2-aminocyclopentan-1-ol **129** and 4-bromobutyryl chloride **64** was attempted using Schotten-Baumann conditions (see Scheme 25). However, a large number of impurities were observed by LCMS (see Figure 25), and so three new strategies were attempted: protection of the alcohol (see 4.5.3), installing the linker on methyl ciprofloxacin **108** and then attaching the head group by peptide coupling (see 4.5.4), and using 4-chlorobutyryl chloride **153** as the linker instead of 4-bromobutyryl chloride **64** (see 4.5.5).



Scheme 25: Attempted synthesis of Br-C₄-cyclopentanol-(*SS*) **131**. a) NaHCO₃, CH₂Cl₂, H₂O, 0 °C, 2 h.

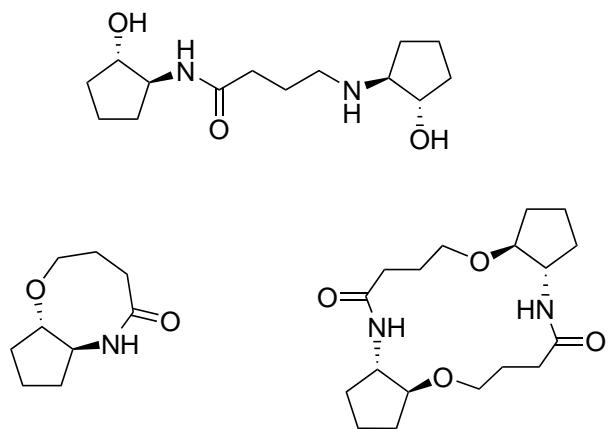
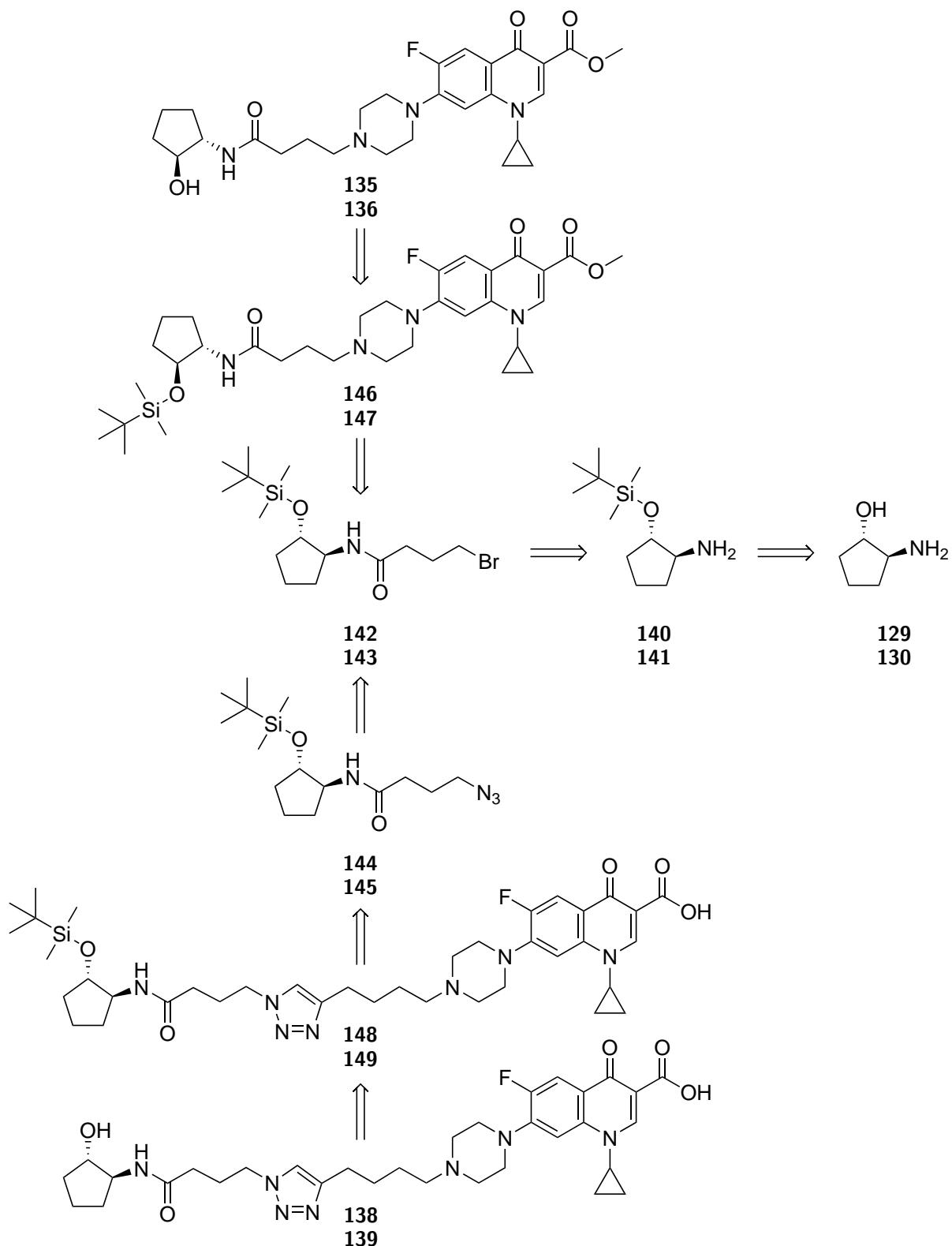


Figure 25: Impurities observed by LCMS during the synthesis of Br-C₄-cyclopentanol-(SS) **131**. Regiochemistry is speculative.

4.5.3 TBDMS protection route

The first attempt at an alternative strategy for the synthesis of the conjugates involved TBDMS protection of the alcohol (see Scheme 26). It was envisaged that protection would eliminate enough of the side reactions with products shown in Figure 25 that intermediates Br-C₄-cyclopentanol-(SS) **131** and N₃-C₄-cyclopentanol-(SS) **133** could be purified. The TBDMS group could be removed later in the synthesis using TBAF or acid.

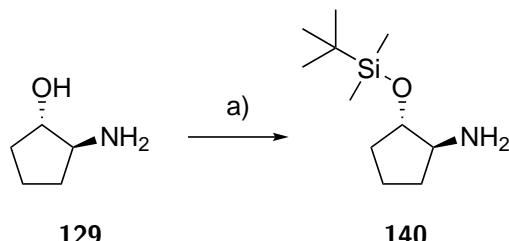


Scheme 26: Retrosynthetic of the cyclopentanol-CipMe conjugates **135** (*SS*) and **136** (*RR*), and the cyclopentanol-Cip triazole conjugates **138** (*SS*) and **139** (*RR*) using a TBDMS protection strategy. *SS* enantiomers are shown, but both are implied.

4.5.3.1 Synthesis of TBDMS-protected (1*S*,2*S*)-2-aminocyclopentan-1-ol **129**

The synthesis began with the optimisation of the protection of (1*S*,2*S*)-2-aminocyclopentan-1-ol **129** with a TBDMS group on the alcohol (see Scheme 28). This reaction proved more problematic than expected, possibly

due to the amine group interfering with the reaction at the alcohol and/or the high polarity of the starting material causing problems with solubility in the reaction mixture and extraction during the work-up. Conditions attempted are summarised in Table 10. Protection attempts using TBDMSCl were generally unsuccessful, but eventually a method employed by Wu et. al¹⁷⁰ using TBDMSCl was found to produce the desired product in excellent yield. Water was used for the work-up rather than NH₄Cl (sat. aq.), as the acidic work-up protonated the product. The TEA was removed during column chromatography instead.



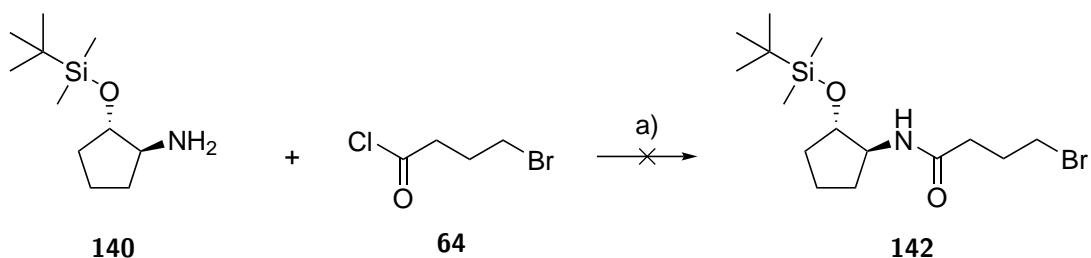
Scheme 27: Synthesis of TBDMS protected (*1S,2S*)-2-aminocyclopentan-1-ol **140**. a) See Table 10.

Conditions	Temperature	Time	Result
TBDMSCl, DMAP, TEA, CH_2Cl_2 ¹⁷¹	r.t.	18 h	Trace of 140 , mostly 129
TBDMSCl, imidazole, CH_2Cl_2 ¹⁷²	0 °C	1 h	129
TBDMSCl, DBU, MeCN ¹⁷³	0 °C	1 d	129
TBDMSOTf, TEA, CH_2Cl_2 , ¹⁷⁰ aq. workup then column	0 °C	6 h	140 , 97.7 % yield

Table 10: Conditions attempted for the synthesis of $(1S,2S)$ -2-((*tert*-butyldimethylsilyl)oxy)cyclopentan-1-amine **140** (see Scheme 28).

4.5.3.2 Synthesis of Br-C₄-cyclopentanol-TBDMS-(SS) 142

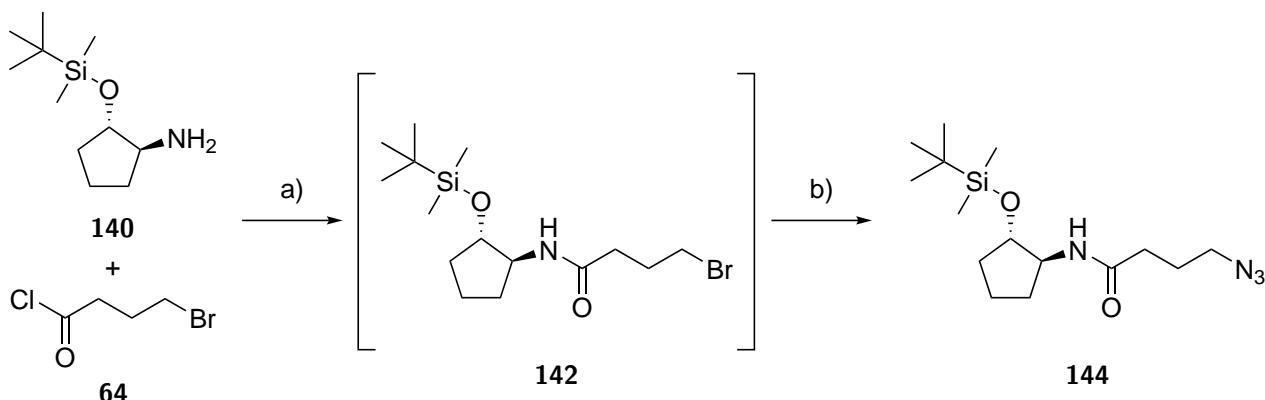
The TBDMS protected (1*S*,2*S*)-2-aminocyclopentan-1-ol **140** was reacted with 4-bromobutyryl chloride **64** to form Br-C₄-cyclopentanol-TBDMS-(*SS*) **142**. The reaction was observed to go to completion by TLC, but it became apparent that the product was reacting further during concentration and purification. Adding sodium azide to the mixture obtained after the failed purification attempts was observed to convert the remaining Br-C₄-cyclopentanol-TBDMS-(*SS*) **142** to N₃-C₄-cyclopentanol-TBDMS-(*SS*) **144**. A sequential one-pot reaction was therefore used, so that the reactive intermediate did not need to be isolated.



Scheme 28: Attempted synthesis of Br-C₄-cyclopentanol-TBDMS-(SS) **142**. a) NaHCO₃, CH₂Cl₂, H₂O, 0 °C, 2 h.

4.5.3.3 Synthesis of $\text{N}_3\text{-C}_4\text{-cyclopentanol-TBDMS-(SS) 144}$ by one-pot reaction

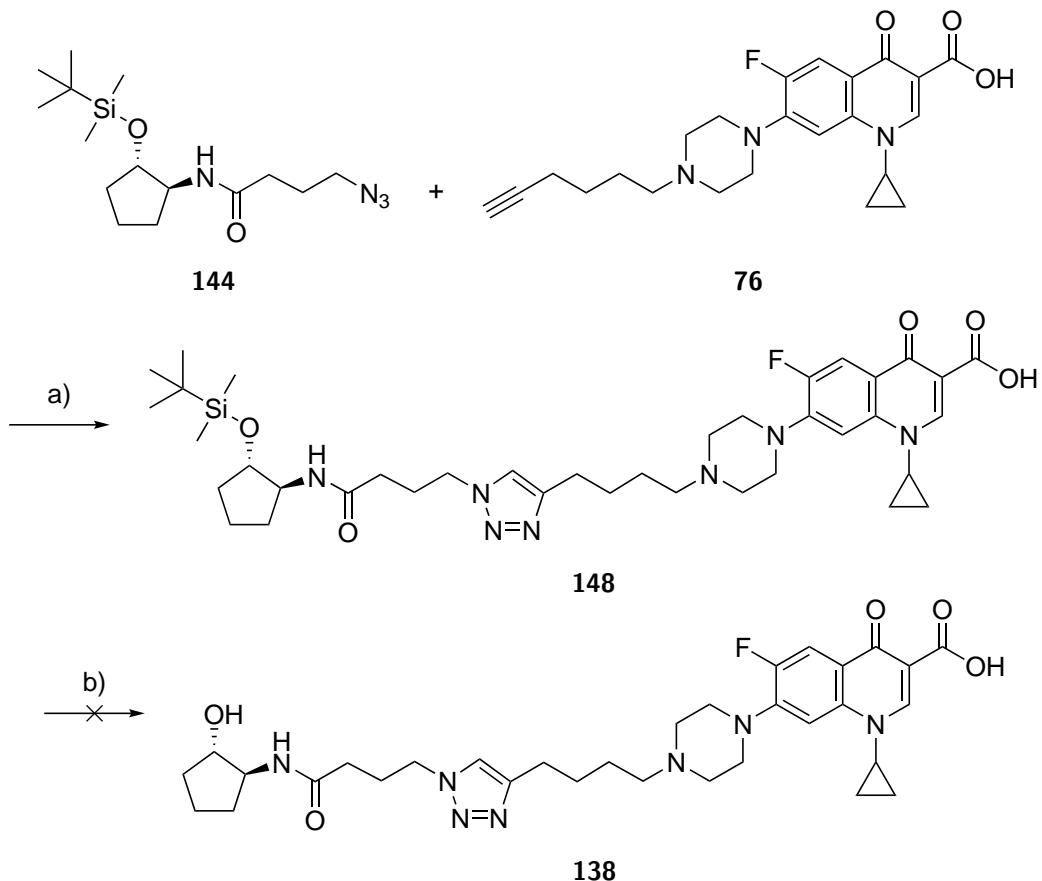
$\text{N}_3\text{-C}_4\text{-cyclopentanol-TBDMS-(SS) 144}$ was finally synthesised by a two-step, one-pot reaction. Schotten-Baumann conditions were used to form the bromide. The water was then removed, and DMF and sodium azide were added. $\text{N}_3\text{-C}_4\text{-cyclopentanol-TBDMS-(SS) 144}$ was produced in excellent yield.



Scheme 29: Synthesis of $\text{N}_3\text{-C}_4\text{-cyclopentanol-TBDMS-(SS) 144}$. a) NaHCO_3 , CH_2Cl_2 , H_2O , 0°C , 3 h. b) NaN_3 , DMF , CH_2Cl_2 , r.t., 3 h. 99.2 % over 2 steps.

4.5.3.4 Synthesis of the (SS)-TBDMS-cyclopentanol-Cip triazole conjugate **148**

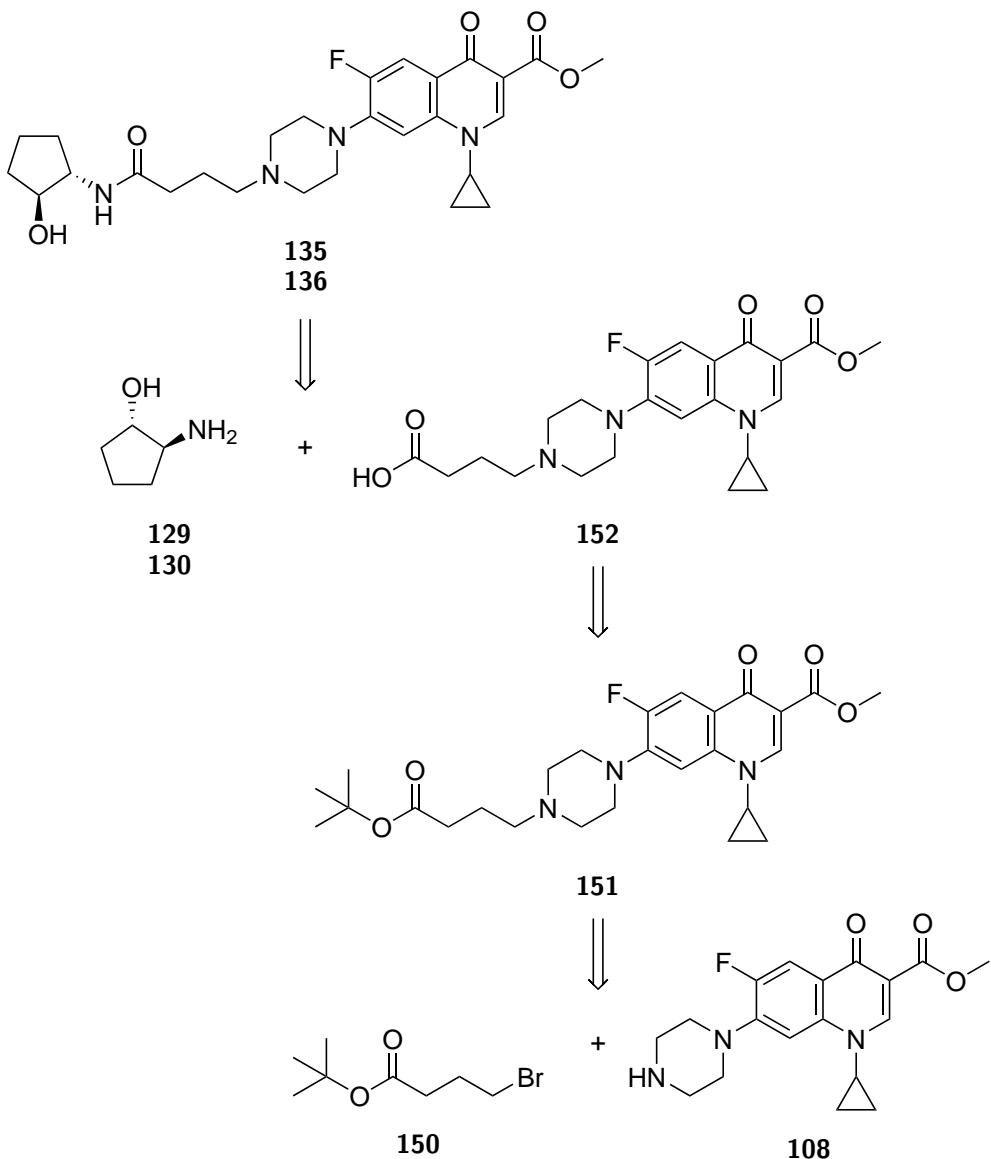
$\text{N}_3\text{-C}_4\text{-cyclopentanol-TBDMS-(SS) 144}$ and the alkynyl ciprofloxacin derivative **76** were subjected to standard click conditions (see 5.25), and the (SS)-TBDMS-cyclopentanol-Cip triazole conjugate **148** was synthesised in very good yield. However, removal of the TBDMS group proved difficult. Deprotection using 1.5 eq. TBAF in THF proceeded slowly, reaching completion in 5 d. Increasing the amount of TBAF to 8 eq. allowed the reaction to proceed overnight. Purification of the final conjugate **138** by column chromatography was not successful due to streaking and poor separation. Purification using DOWEX resin and CaCO_3^{174} was attempted, but the product could not be recovered from the resin. The purification method could probably be optimised, e.g. by varying the solvent used with the resin, but ultimately this route was abandoned due to the reduction in number of steps afforded by the two methods described below.



Scheme 30: Synthesis of the (SS)-TBDMS-cyclopentanol-Cip triazole conjugate **148**. a) CuSO_4 , sodium ascorbate, THPTA, H_2O , *t*-BuOH, r.t., 87.4 %. b) TBAF, THF, r.t., 16 h.

4.5.4 Synthesis of the cyclopentanol-CipMe conjugates **135** and **136** by peptide coupling

Given the side-reactions and low yields associated with the literature synthesis of the S_N2 conjugates proposed by Ganguly et. al,¹³⁴ an alternative synthesis was investigated, involving building up the linker on the ciprofloxacin side before coupling with the head group (see Scheme 31).



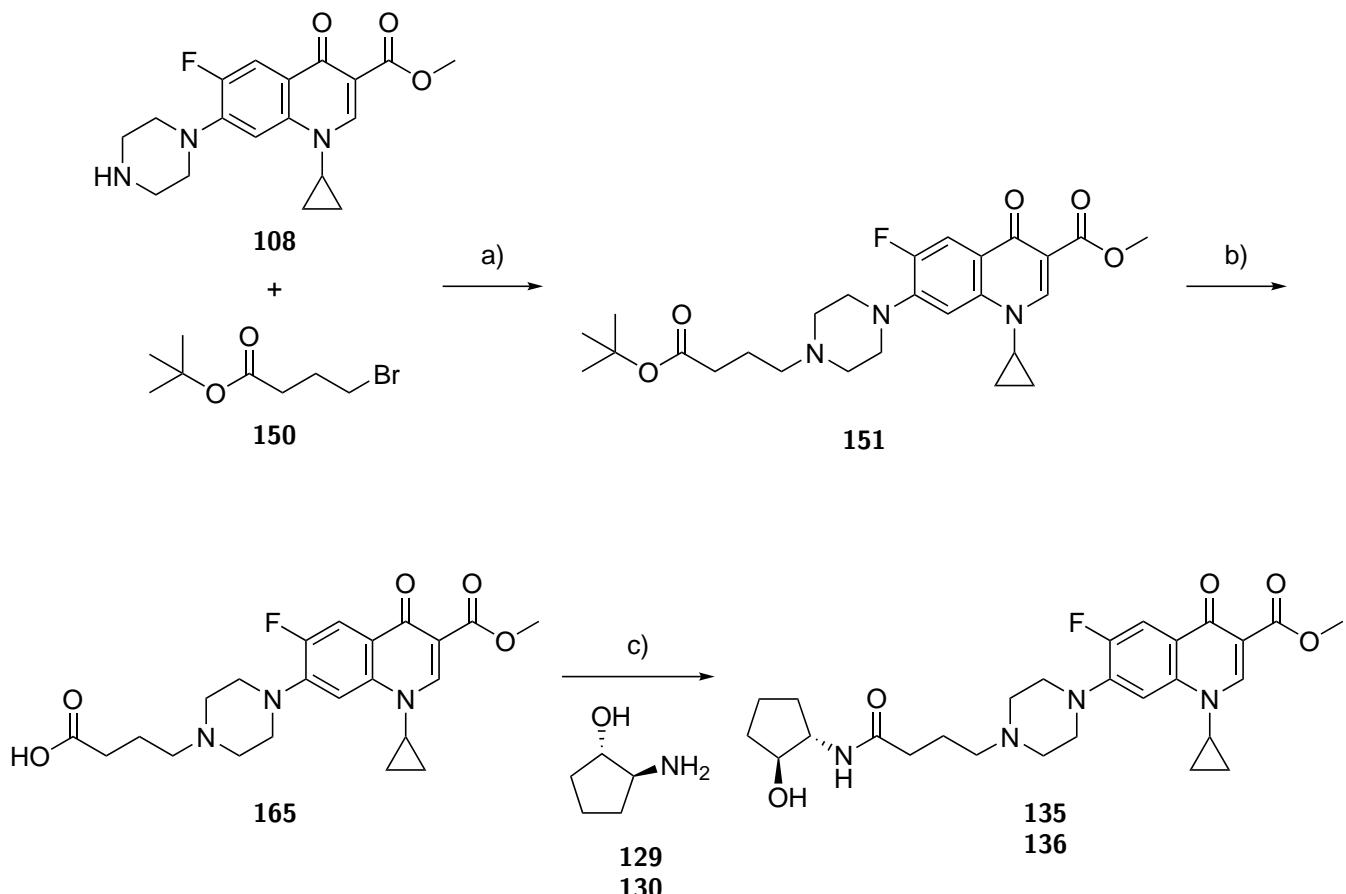
Scheme 31: Retrosynthesis of the cyclopentanol-CipMe conjugates **135** (*SS*) and **136** (*RR*). *SS* enantiomers are shown, but both are implied.

The first step of the synthesis was an S_N2 reaction between Boc-protected 4-bromobutyric acid **150** methyl ciprofloxacin **108** (see Scheme 32). This reaction used fairly harsh conditions (16 h at 100 °C), but early on in the synthesis before the head group was installed. Hence the possibility of side reactions between the bromide and the amine was removed. Intermediate **151** was obtained in acceptable yield after column chromatography (49.9 %). Intermediate **151** was deprotected in excellent yield using TFA in CH_2Cl_2 to give carboxylic acid **152**. Scale-up of this reaction allowed the easy synthesis of 600 mg of this useful intermediate, which can be coupled with various amine head-groups to create a library. Carboxylic acid **152** was first coupled with (*1R,2R*)-2-aminocyclopentan-1-ol **130** using standard peptide coupling conditions to give cyclopentanol-CipMe conjugate **136**. Purification by column chromatography was attempted twice with poor results, before moving on to using preparative HPLC, which gave **136** cleanly in 38.7 % yield. Coupling was also performed with (*1S,2S*)-2-aminocyclopentan-1-ol **129** to give the enantiomer **135** in 54.7 % yield.

Direct comparisons of routes are not possible without repeating syntheses using this new method, but if it is assumed that peptide coupling of homocysteine thiolactone hydrochloride **109** to carboxylic acid **152** would have a similar yield to the coupling with (*1R,2R*)-2-aminocyclopentan-1-ol **130**, approximate comparisons can be made. The synthesis described in 4.2 has an overall yield of 10.7 %, whereas the route shown in Scheme 32

for **135** has an overall yield of 26.1 %. Moreover, if the yield starting from the head group (which may be expensive, difficult to synthesise and/or unstable) is considered, the yield is 54.7 % vs. 10.7 %. Therefore, this route is recommended for further investigation if the library is to be expanded.

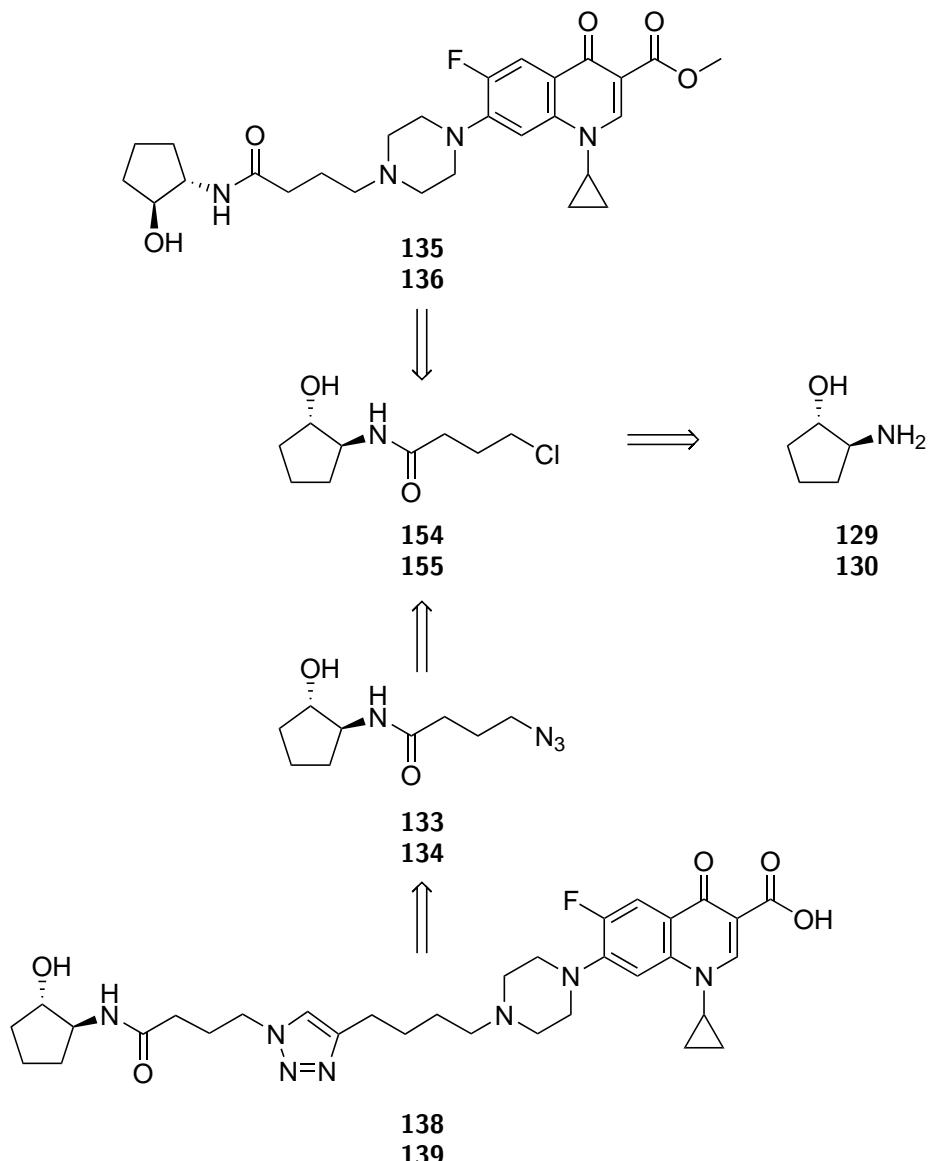
A downside to this route is that it cannot branch towards the triazole-coupled library in the same way that the route in 4.2. A carboxylic acid intermediate with a triazole in the chain could presumably be synthesised, but this would be rather pointless given that the triazole library was initially proposed so that the two sides could be joined by the click reaction. Therefore, an alternative route to the azide was proposed, via a more stable chloride intermediate (see 4.5.5).



Scheme 32: Synthesis of the cyclopentanol-CipMe conjugates **135** (*SS*) and **136** (*RR*) by peptide coupling. *SS* enantiomers are shown, but both were synthesised. a) NaI, TEA, acetonitrile, 100 °C, 16 h, 49.9 %. b) TFA, CH₂Cl₂, r.t., 18 h, 95.6 %. c) EDC, HOEt, DIPEA, DMF, r.t., 16 h, **135** (*SS*): 54.7 %, **136** (*RR*): 38.7 %.

4.5.5 Synthesis of the cyclopentanol-Cip triazole conjugates **138** and **139** via chloride intermediates

A final attempt at a branching strategy was attempted, via a chloride rather than a bromide intermediate (see Scheme 33 and Scheme 24 for comparison). The bromide intermediate was initially chosen as it was used by Ganguly et. al.¹³⁴ but it was hoped that using a chloride would cut out some of the side reactions seen with the more reactive bromide.



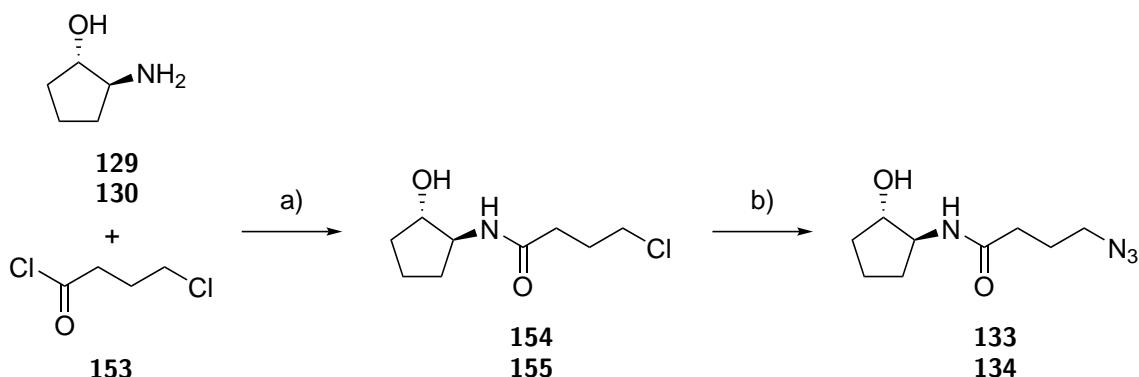
Scheme 33: Retrosynthesis of the cyclopentanol-CipMe conjugates **135** (SS) and **136** (RR), and the cyclopentanol-Cip triazole conjugates **138** (SS) and **139** (RR) via Cl-C₄-cyclopentanol intermediates **154** (SS) and **155** (RR). *SS* enantiomers are shown, but both are implied.

Attempts at this route began with the synthesis of Cl-C₄-cyclopentanol-(RR) **155**. Standard Schotten-Baumann conditions failed to produce significant amounts of product. If prolonged reaction times were allowed, degradation of the acid chloride to the carboxylic acid was observed. The reason for this is unclear, but it is possible that bromide ions present in small amounts in previous reactions were helping to catalyse the reaction of the acid chloride. Archer *et al.*¹⁷⁵ propose that bromide ions can react with acid chlorides to form acid bromides, which are then more susceptible to nucleophilic attack. As no bromide ions are present in this reaction, different conditions were sought in order to increase the rate.

As (1*R*,2*R*)-2-aminocyclopentan-1-ol **130** is fairly polar, it is likely that it was staying in the aqueous layer to some extent even when deprotonated, thus keeping the two reactants apart. Therefore, the solvent system and base were changed to neat CH₂Cl₂ and TEA. This produced Cl-C₄-cyclopentanol-(RR) **155** in good yield (64.1 %). Unlike the bromide **131**, the chloride **155** was stable when concentrated.

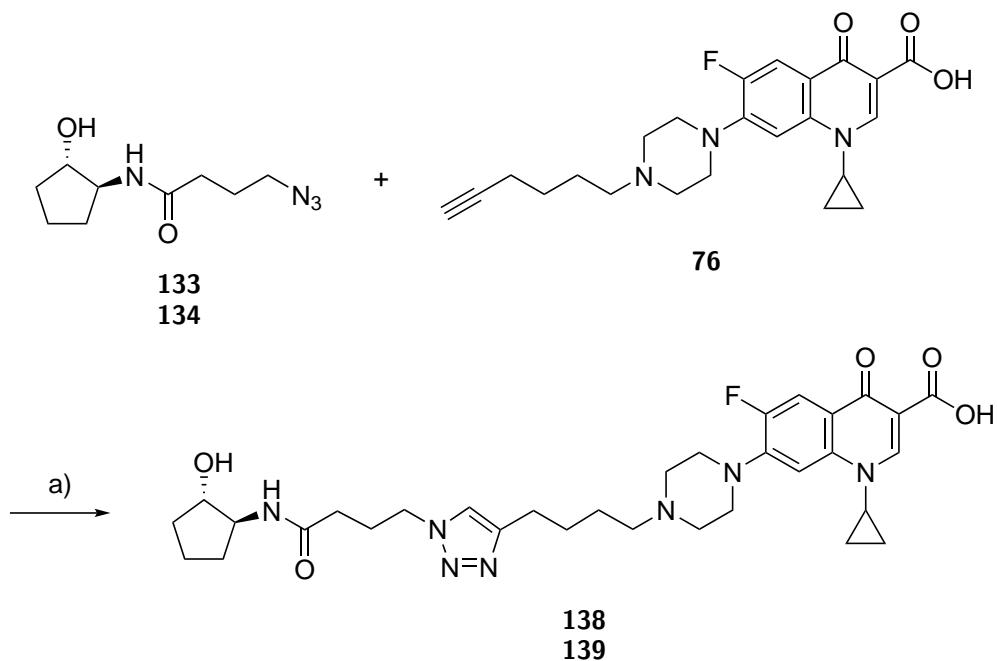
Cl-C₄-cyclopentanol-(RR) **155** was converted to N₃-C₄-cyclopentanol-(RR) **134** by reaction with sodium azide. The reaction was slower than with previous bromides (~16 h vs. ~2 h), but much cleaner than with Br-C₄-cyclopentanol-(SS) **131** (see 4.5.2).

The enantiomers Cl-C₄-cyclopentanol-(*SS*) **154** and N₃-C₄-cyclopentanol-(*SS*) **133** were synthesised in lower yields, in part because of the smaller amounts being used.



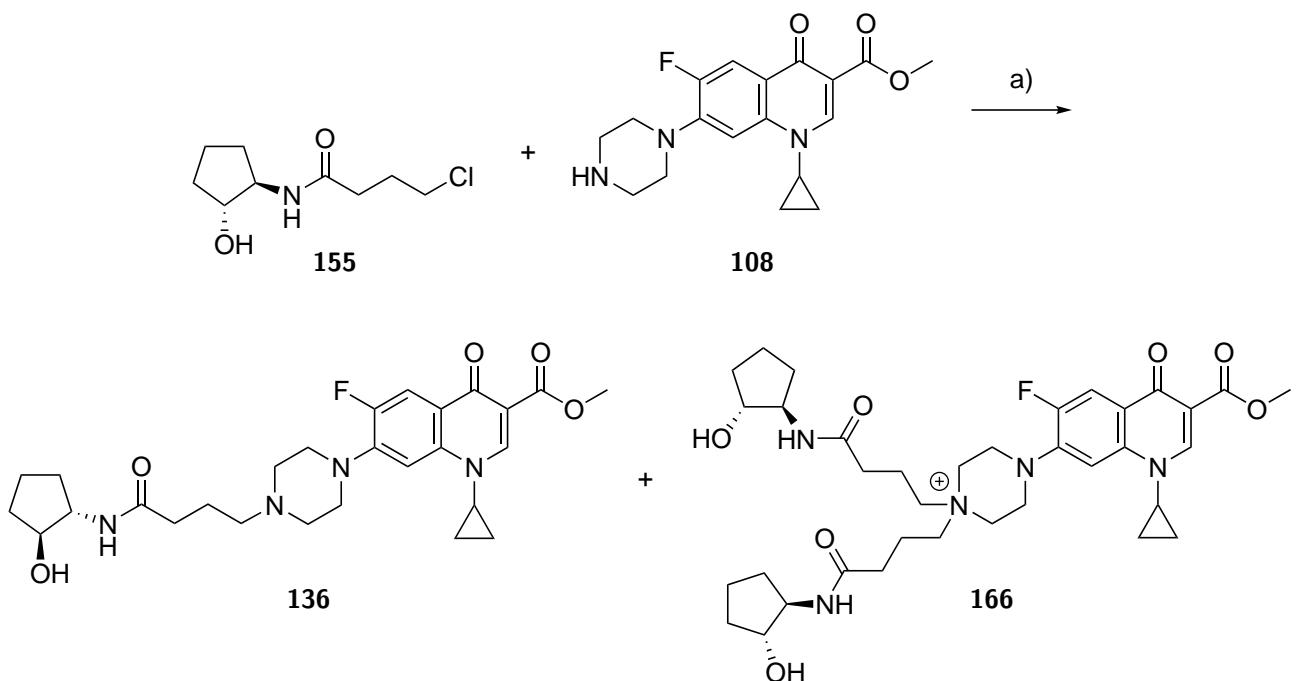
Scheme 34: Synthesis of N₃-C₄-cyclopentanol-(*SS*) **133** and N₃-C₄-cyclopentanol-(*RR*) **134**. *SS* enantiomers are shown, but both were synthesised. a) TEA, CH₂Cl₂, 0 °C, 2 h, **154** (*SS*): 24.2 %, **155** (*RR*): 64.1 %. b) NaN₃, acetonitrile, 50 °C, 16 h, **133** (*SS*): 45.0 %, **134** (*RR*): 87.6 %.

The cyclopentanol-Cip triazole conjugates **138** (*SS*) and **139** (*RR*) were synthesised using standard click conditions (see 5.25). Yields were poor primarily due to problems with purification, including losses on the preparative HPLC column and high polarity leading to losses during extraction from aqueous solvents. However, as enough of the compounds was obtained for biological testing the purification was not optimised further.



Scheme 35: Synthesis of the cyclopentanol-Cip triazole conjugates **138** (*SS*) and **139** (*RR*). *SS* enantiomers are shown, but both were synthesised. a) CuSO₄, THPTA, sodium ascorbate, H₂O, *t*-BuOH, r.t., 16 h, **138** (*SS*): 22.2 %, **139** (*RR*): 27.1 %.

The S_N2 reaction of Cl-C₄-cyclopentanol-(*RR*) **155** and methyl ciprofloxacin **108** was attempted (see Scheme 36) using the microwave conditions described previously (see 4.3), to see if the chloride produced better results compared with the bromide. However, as was seen with the other microwave reactions, a substantial amount of the disubstituted product **164** was seen by LCMS (in an approx 1:1 ratio with the desired product **165**). As a higher-yielding route had already been found (see 4.5.4), this route was abandoned.



Scheme 36: Attempted synthesis of the cyclopentanol-CipMe-(RR) conjugate **136**. a) NaI , DIPEA , acetonitrile, microwave reactor, $100\text{ }^\circ\text{C}$.

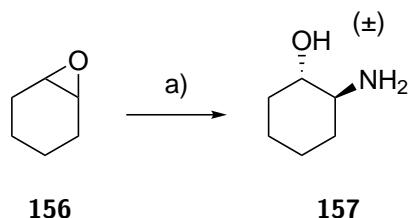
With (unfortunately not branching) routes to the S_N2 and click conjugates established (see 4.5.4 and 4.5.5 respectively), attention was turned to the cyclohexanol derivatives.

4.6 Cyclohexanol derivatives

4.6.1 Synthesis of the *trans*-2-aminocyclohexan-1-ol head group **157**

It was decided to produce the cyclohexanol conjugates racemically, with the option of re-synthesising enantiomerically pure versions via the route shown in 4.5.1 if the compounds showed biological activity.

Production of the cyclohexanol conjugates began with the synthesis of *trans*-2-aminocyclohexan-1-ol **157** (see Scheme 37), using a procedure reported by Xue *et al.*¹⁷⁶ Cyclohexene oxide **156** was opened using ammonia in water and methanol. Initially the reaction was carried out at $85\text{ }^\circ\text{C}$ in a microwave reactor for 30 min, but a large amount of the disubstituted amine could be seen by LCMS (in a ratio of 4:3 product to impurity by NMR). The reaction was therefore attempted at room temperature, and proceeded overnight in high yield and with minimal side reaction.

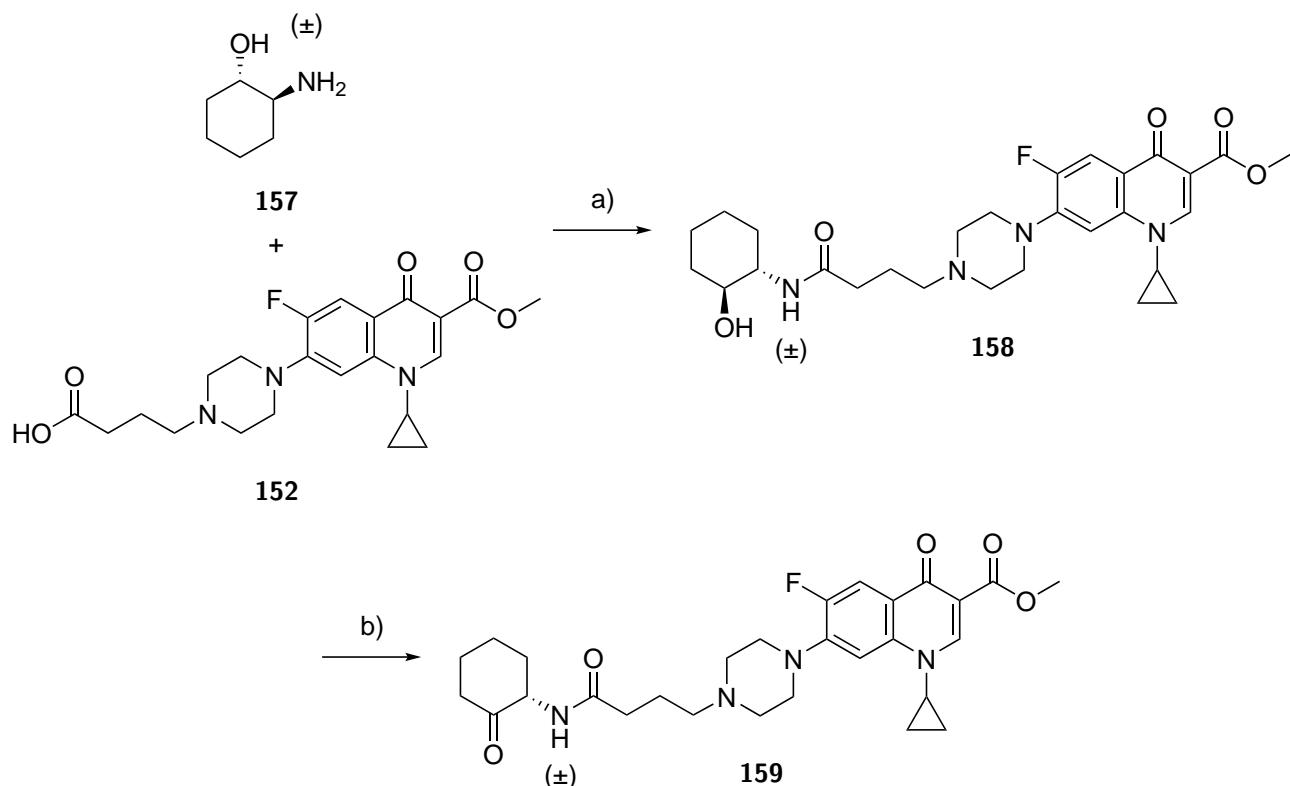


Scheme 37: Synthesis of *trans*-2-aminocyclohexan-1-ol **157**. a) NH_3 , water, MeOH , r.t., 72 h, 86.2 %.

4.6.2 Synthesis of the *trans*-cyclohexanol- and cyclohexanone-CipMe conjugates **158** and **159**

Carboxylic acid **152** was coupled with *trans*-2-aminocyclohexan-1-ol **157** using standard peptide coupling conditions to give *trans*-cyclohexanol-CipMe conjugate **158** in 31.7 % yield. Again, losses during purification appear to be the main cause of this poor yield.

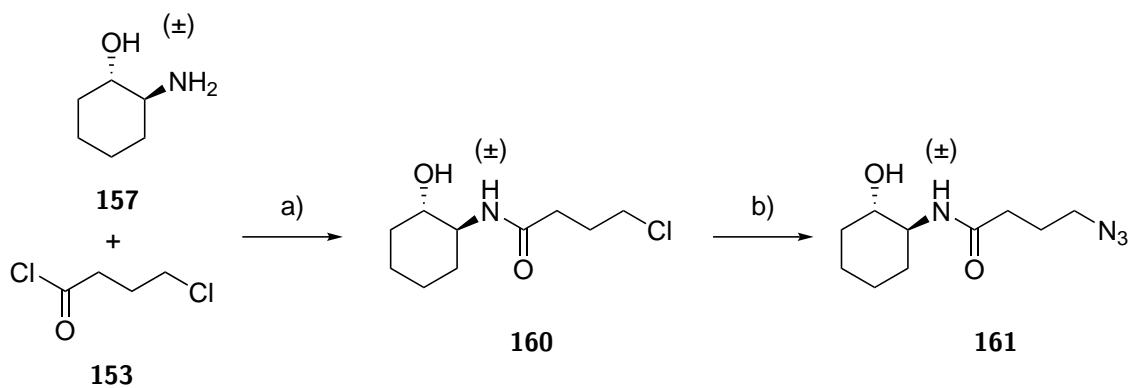
A portion of the *trans*-cyclohexanol-CipMe conjugate **158** was then oxidised to the ketone using Dess-Martin periodinane. The product was isolated in good yield, perhaps due to the compound being less polar and hence easier to purify.



Scheme 38: Synthesis of the cyclohexanol-CipMe conjugate **158** and the cyclohexanone-CipMe conjugate **159**.
a) EDC, HOBr, DIPEA, DMF, r.t., 16 h, 31.7 %. b) DMP, CH_2Cl_2 , r.t., 6 h, 69.1 %.

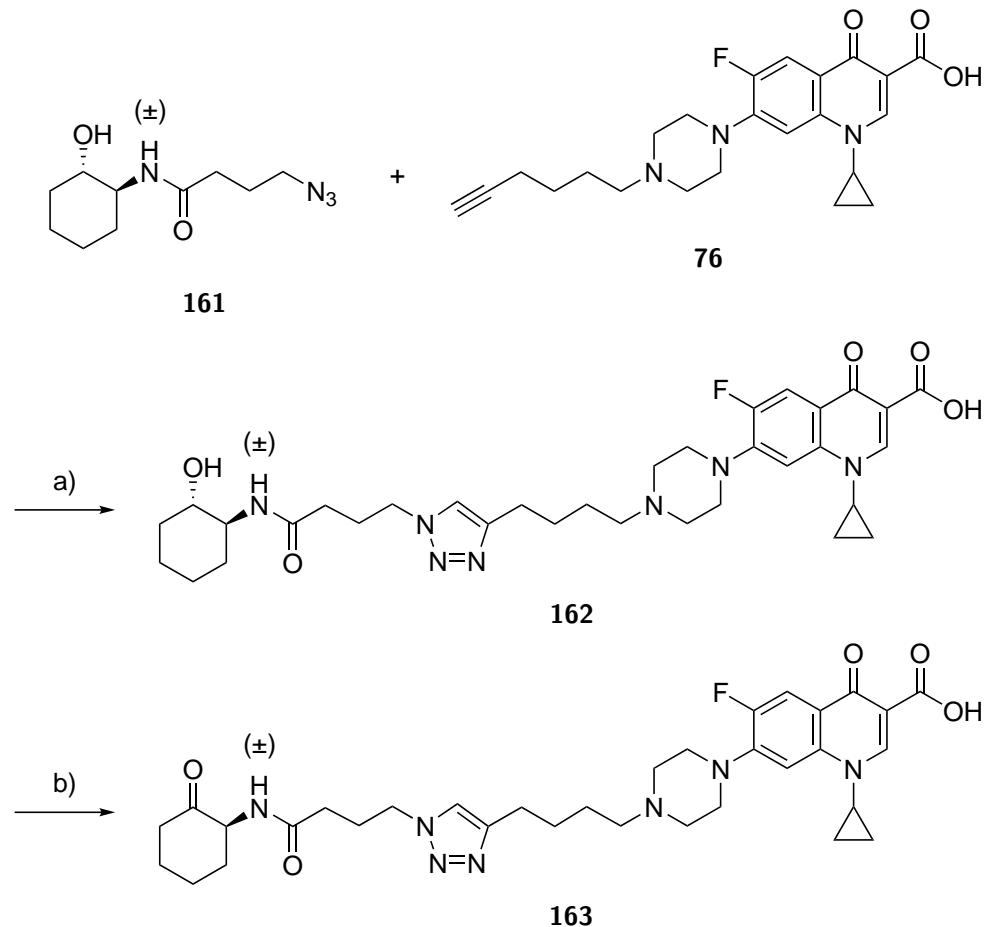
4.6.3 Synthesis of the *trans*-cyclohexanol- and cyclohexanone-Cip triazole conjugates **162** and **163**

The triazole conjugates were synthesised using the route described in 4.5.5. Cl-C₄-*trans*-cyclohexanol **160** was synthesised in good yield from *trans*-2-aminocyclohexan-1-ol **157** and 4-chlorobutyryl chloride **153**. Cl-C₄-*trans*-cyclohexanol **160** was then converted to N₃-C₄-*trans*-cyclohexanol **161** by reaction with sodium azide in excellent yield.



Scheme 39: Synthesis of *N*₃-C₄-*trans*-cyclohexanol **161**. a) TEA, CH_2Cl_2 , 0°C , 30 min, 76.1 %. b) NaN_3 , acetonitrile, 50°C , 16 h, 97.5 %.

The *trans*-cyclohexanol-Cip conjugate **162** was synthesised using standard click conditions (see 5.2.5) in 48.9 % yield. A portion of the *trans*-cyclohexanol-Cip conjugate **162** was then oxidised to the ketone using the same conditions used for the cyclohexanone-CipMe conjugate (see 4.6.2) in very good yield.



Scheme 40: Synthesis of the *trans*-cyclohexanol-Cip triazole conjugate **162** and the cyclohexanone-Cip triazole conjugate **163**. a) CuSO_4 , THPTA, sodium ascorbate, H_2O , *t*-BuOH, r.t., 16 h, 48.9 %. b) DMP, CH_2Cl_2 , r.t., 4 h, 78.0 %.

5 Experimental

5.1 General

Unless otherwise stated, reactions were performed in air-dried glassware under argon with dry, freshly-distilled solvents. THF was distilled from LiAlH₄ in the presence of triphenyl methane indicator. CH₂Cl₂, hexane, MeOH and MeCN were distilled from calcium hydride. All other chemicals were used as obtained from commercial sources.

Reactions using microwave heating were performed in sealed vials using a CEM Discover SP microwave reactor.

Thin Layer Chromatography (TLC) was performed using Merck pre-coated 0.23 mm thick plates of Keisel-gel 60 F254 and visualised using UV ($\lambda = 254$ or 366 nm) or by staining with KMnO₄ or ninhydrin. All retention factors (R_f) are given to 0.01. All column chromatography was carried out using Merck 9385 Keisel-gel 60 silica gel (230-400 mesh) or using a CombiFlash® EZ Prep with RediSep® normal-phase silica flash columns. Preparative High Pressure Liquid Chromatography was run on an Agilent 1260 Infinity machine, using a Supelcosil™ ABZ+PLUS column (250 mm \times 21.2 mm, 5 μ m) with a linear gradient system (solvent A: 0.1 % (v/v) TFA/water, solvent B: 0.05 % (v/v) TFA/acetonitrile) at a flow rate of 20 mL min⁻¹, visualised by UV absorbance ($\lambda_{max} = 254$ nm)

Nuclear Magnetic Resonance (NMR) spectra were recorded using an internal deuterium lock at ambient probe temperatures on Bruker DPX-400, Bruker Avance DRX-400, Bruker Avance 500 BB-ATM or Bruker Avance 500 Cryo Ultrashield spectrometers. Data were processed using NMR Processor Academic Edition version 12 (ADC Labs) or TopSpin version 3.5 (Bruker). ¹H and ¹³C spectra were assigned using DEPT, COSY, HMQC and HMQC spectra where necessary, or by analogy to fully interpreted spectra of related compounds. The following abbreviations are used to indicate the multiplicity of signals: s singlet, d doublet, t triplet, q quartet, quin quintet, m multiplet and br broad.

¹H chemical shifts (δ) are quoted to the nearest 0.01 ppm and are referenced relative to the residual solvent peak.¹⁷⁷ Coupling constants (J) are given to the nearest 0.1 Hz. Diastereotopic protons are assigned as CHH and CH_H, where the latter designates the lower-field proton. Data are reported as follows: <chemical shift> (<multiplicity>, <coupling constant(s) (if any)>, <integration>, <assignment>).

¹³C chemical shifts (δ) are quoted to the nearest 0.1 ppm and are referenced relative to the deuterated solvent peak.¹⁷⁷ Data are reported as follows: <chemical shift> (<multiplicity (if not s)>, <coupling constant(s) (if any)>, <assignment>).

¹⁹F chemical shifts (δ) are quoted to the nearest 0.1 ppm. Data are reported as follows: <chemical shift> (<assignment>).

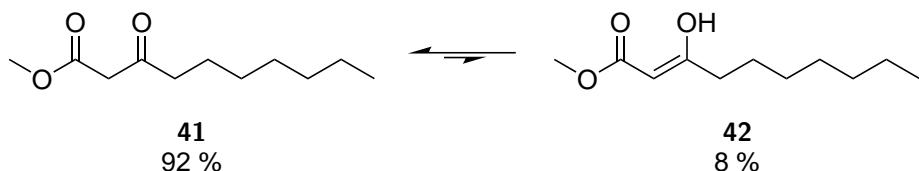
High Resolution Mass Spectra (HRMS) were recorded using a Micromass LCT Premier spectrometer or a Waters Vion IMS-QTOF spectrometer and reported mass values are within ± 5 ppm mass units. Low Resolution Mass Spectra (LRMS) were recorded on an Agilent 1200 series LC with an ESCi Multi-Mode Ionisation Waters ZQ spectrometer or a Waters ACQUITY H-Class UPLC with an ESCi Multi-Mode Ionisation Waters SQD2 mass spectrometer.

Infra Red (IR) spectra were recorded using neat sample on a PerkinElmer 1600 FT IR spectrometer. Selected absorption maxima (ν_{max}) are reported in wavenumbers (cm⁻¹). Broad peaks are marked br.

Melting points (m.p.) were measured using a Buchi B-545 melting point apparatus and are uncorrected.

Optical rotations ($[\alpha]_D^T$) were recorded on a PerkinElmer 343 polarimeter or an Anton-Paar MCP 100 polarimeter. $[\alpha]_D^T$ values are reported in ${}^{\circ}10^{-1}\text{cm}^2\text{g}^{-1}$ at 589 nm and concentration (c) is given in g (100 mL)⁻¹.

5.2 Methyl 3-oxodecanoate 41



Meldrum's acid **39** (9.0 g, 63 mmol, 1 eq.) was dissolved in anhydrous CH_2Cl_2 (150 ml) in an oven-dried flask and cooled to 0 °C. Pyridine (10.2 ml, 126 mmol, 2 eq.) was added dropwise over 20 min. Octanoyl chloride **40** (11.7 ml, 69 mmol, 1.1 eq.) was then added and the mixture was stirred at 0 °C for a further 4 h. The mixture was allowed to warm to r.t., diluted with CH_2Cl_2 (20 ml) and poured into a mixture of ice (~30 g) and HCl (2 N, 90 ml). The solution was washed with NaCl (sat., aq., 150 ml) and dried over MgSO_4 . The solvent was removed under vacuum to give an orange-brown oil. The oil was refluxed in anhydrous MeOH (150 ml) for 5 h and the solvent was removed under vacuum. The resulting residue was purified by column chromatography (SiO_2 , 5 % $\text{Et}_2\text{O}/40\text{-}60$ P.E.). A tautomeric mixture of **41** and **42** was obtained as a colourless oil (8.34 g, 41.6 mmol, 66 %, 92 % **41** as determined by ^1H NMR).

Keto form **41**

TLC R_f = 0.12 (5 % EtO_2/PE)

IR (neat) ν_{max} / cm^{-1} = 2927.8 (C-H), 2856.3 (C-H), 1746.9 (ester C=O), 1716.7 (ketone C=O)

^1H NMR (400 MHz, CDCl_3) δ / ppm = 3.74 (s, 3 H, OCH_3), 3.45 (s, 2 H, $\text{C}(=\text{O})\text{CH}_2\text{C}(=\text{O})$), 2.53 (t, J = 7.4 Hz, 2 H, $\text{C}(=\text{O})\text{CH}_2\text{CH}_2$), 1.60 (quin, J = 7.1 Hz, 2 H, $\text{C}(=\text{O})\text{CH}_2\text{CH}_2$), 1.39 - 1.19 (m, 8 H, $\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$), 0.88 (t, J = 6.8 Hz, 3 H, CH_2CH_3)

^{13}C NMR (101 MHz, CDCl_3) δ / ppm = 202.3 ($\text{CH}_3\text{OC}(=\text{O})\text{CH}_2\text{C}(=\text{O})$), 167.3 ($\text{CH}_3\text{OC}(=\text{O})\text{CH}_2\text{C}(=\text{O})$), 51.7 (OCH_3), 48.5 ($\text{CH}_3\text{OC}(=\text{O})\text{CH}_2\text{C}(=\text{O})$), 42.5 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2$), 31.3 (CH_2), 28.7 (CH_2), 28.6 (CH_2), 23.1 (CH_2), 22.2 (CH_2), 13.6 (CH_2CH_3)

Enol form **42**

TLC R_f = 0.12 (5 % EtO_2/PE)

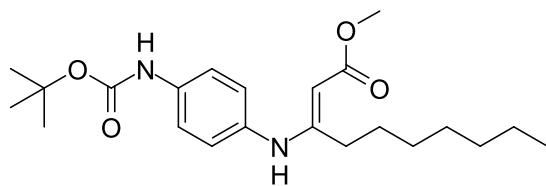
IR (neat) ν_{max} / cm^{-1} = 2927.8 (C-H), 2856.3 (C-H), 1653.8 (C=C), 1629.2 (α,β unsaturated C=O)

^1H NMR (400 MHz, CDCl_3) δ / ppm = 12.02 (s, 1 H, COH), 4.99 (s, 1 H, $\text{C}(=\text{O})\text{CH}=\text{COH}$), 3.73 (s, 3 H, OCH_3), 2.20 (t, J = 7.4 Hz, 2 H, COHCH_2), 1.76 - 1.72 (m, 2 H, $\text{COHCH}_2\text{CH}_2$), 1.39 - 1.19 (m, 8 H, $\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$), 0.88 (t, J = 6.8 Hz, 3 H, CH_2CH_3)

^{13}C NMR (101 MHz, CDCl_3) δ / ppm = 178.7 ($\text{CH}_3\text{OC}(=\text{O})\text{CH}=\text{COH}$), 172.7 ($\text{CH}_3\text{OC}(=\text{O})\text{CH}=\text{COH}$), 88.2 ($\text{CH}_3\text{OC}(=\text{O})\text{CH}=\text{COH}$), 50.5 (OCH_3), 37.9 ($\text{COHCH}_2\text{CH}_2$), 34.6 (CH_2), 31.2 (CH_2), 29.0 (CH_2), 25.9 (CH_2), 22.3 (CH_2), 13.6 (CH_2CH_3)

Spectroscopic data are consistent with the literature.^{153,154}

5.3 Methyl (E)-3-((4-((*tert*-butoxycarbonyl)amino)phenyl)amino)dec-2-enoate 44



Methyl 3-oxodecanoate **41** (500 mg, 2.50 mmol, 1.00 eq.) and *O*-*tert*-butyl *N*-(4-aminophenyl)carbamate **43** (520 mg, 2.50 mmol, 1.00 eq.) were dissolved in MeOH (10 ml) and refluxed for 18 h. The solvent was removed under vacuum and the resulting residue was purified by column chromatography (SiO₂, gradient of 0 to 20 % Et₂O/40-60 P.E.). **44** was obtained as a white amorphous solid (0.169 mg, 0.480 mmol, 19 %).

TLC R_f = 0.30 (30 % Et₂O/40-60 P.E.)

mp T / °C = 78.8 (Et₂O/40-60 P.E.)

IR (neat) ν_{max} / cm⁻¹ = 3337.0 (N-H), 2927.7 (C-H), 2857.1 (C-H), 1723.7 (carbamate C=O), 1634.5 (α,β unsaturated C=O), 1610.7 (C=C), 1580.9 (N-H bend)

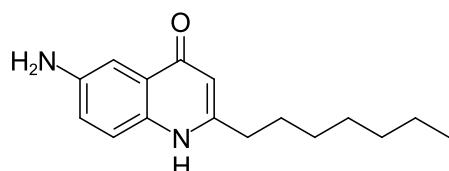
¹H NMR (400 MHz, CDCl₃) δ / ppm = 10.16 (s, 1 H, NHC(C₇H₁₅)=C), 7.35 (d, J = 8.6 Hz, 2 H, *meta* to NHBoc), 7.02 (d, J = 8.7 Hz, 2 H, *meta* to enamine), 6.60 (br s, 1 H, NHBoc), 4.71 (s, 1 H, C=CHC), 3.70 (s, 3 H, OCH₃), 2.23 (t, J = 7.7 Hz, 2 H, CH₂CH₂CH₂CH₂CH₂CH₂CH₃), 1.54 (s, 9 H, C(CH₃)₃), 1.40 (quin, J = 7.3 Hz, 2 H, CH₂CH₂CH₂CH₂CH₂CH₂CH₃), 1.33 - 1.16 (m, 8 H, CH₂CH₂CH₂CH₂CH₂CH₂CH₃), 0.86 (t, J = 7.1 Hz, 3 H, CH₂CH₂CH₂CH₂CH₂CH₃)

¹³C NMR (101 MHz, CDCl₃) δ / ppm = 171.1 (C(=O)CH=C), 164.3 (C(=O)CH=C), 152.7 (OC(=O)NH), 136.0 (*para* to NHBoc), 134.1 (CNHBoc), 126.3 (*meta* to NHBoc), 119.1 (*ortho* to NHBoc), 83.8 (C(=O)CH=C), 80.7 (C(CH₃)₃), 50.2 (OCH₃), 32.2 (CH₂), 31.6 (CH₂), 29.1 (CH₂), 28.8 (CH₂), 28.3 (C(CH₃)₃), 28.0 (CH₂), 22.6 (CH₂), 14.0 (CH₃)

HRMS (ESI⁺) m/z / Da = 391.2589, [M+H]⁺, [C₂₂H₃₅N₂O₄]⁺ requires 391.2591

Spectroscopic data are consistent with the literature.¹⁵⁰

5.4 6-Amino-2-heptylquinolin-4-ol 45



Methyl (E)-3-((4-((*tert*-butoxycarbonyl)amino)phenyl)amino)dec-2-enoate **44** (168 mg, 0.649 mmol, 1 eq.) and polyphosphoric acid (5 g) were heated to 90 °C for 1 h. The reaction mixture was then poured into NaHCO₃ (sat., aq., 50 ml) cooled with ice. The precipitate was collected by vacuum filtration, washed with water (50 ml) and dried under high vacuum. **45** was obtained as a pale yellow amorphous solid (121 mg, 0.468 mmol, 72 %).

mp T / °C = 249 (H₂O)

IR (neat) ν_{max} / cm⁻¹ = 3336.5 (N-H), 2926.5 (C-H), 2856.9 (C-H), 1634.5 (C=O)

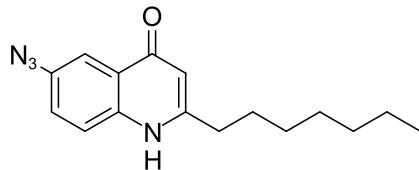
¹H NMR (400 MHz, DMSO-d₆) δ / ppm = 7.26 (d, J = 8.7 Hz, 1 H, *meta* to NH₂), 7.15 (d, J = 2.6 Hz, 1 H, *ortho* to C(=O)), 6.95 (dd, J = 2.7, 8.8 Hz, 1 H, *para* to C(=O)), 5.74 (s, 1 H, *ortho* to CH₂), 5.16 (s, 2 H, NH₂), 2.52 (t, J = 7.4 Hz, 2 H, CCH₂), 1.64 (quin, J = 7.6 Hz, 2 H, CCH₂CH₂), 1.36 - 1.19 (m, 8 H, CH₂CH₂CH₂CH₂CH₃), 0.86 (t, J = 7.0 Hz, 3 H, CH₃)

¹³C NMR (101 MHz, DMSO-d₆) δ / ppm = 176.7 (C(=O)), 151.7 (CCH₂), 145.1 (*para* to NH₂ or *ipso* to C(=O)), 132.4 (*ipso* to NH₂), 126.6 (*para* to NH₂ or *ipso* to C(=O)), 121.1 (*para* to C(=O)), 119.0 (*meta* to NH₂ and *meta* to C(=O)), 106.2 (CH=CCH₂), 105.9 (*ortho* to NH₂ and *ortho* to C(=O)), 33.6 (CCH₂), 31.6 (CH₂CH₂CH₃), 29.0 (CH₂), 29.0 (CH₂), 28.9 (CH₂), 22.5 (CH₂CH₃), 14.4 (CH₃)

HRMS (ESI⁺) m/z / Da = 259.1810, [M+H]⁺, [C₁₆H₂₃N₂O]⁺ requires 259.1803

Spectroscopic data are consistent with the literature.¹⁵⁰

5.5 6-Azido-2-heptylquinolin-4-ol 46



6-Amino-2-heptylquinolin-4-ol **45** (50 mg, 0.194 mmol, 1 eq) was dissolved in HCl (conc., aq., 1.20 ml), water (1.80 ml) and MeOH (2.00 ml) and cooled to 0 °C. A solution of NaNO₂ (16.0 mg, 0.232 mmol, 1.2 eq.) in water (0.300 ml) was added dropwise over 10 min and the mixture was stirred for 1 h. A solution of NaN₃ (15.1 mg, 0.232 mmol, 1.2 eq.) in water (0.300 ml) was then added. The mixture was warmed to room temperature and stirred for a further 4 h. The resultant precipitate was filtered off and dried under reduced pressure. **46** was obtained as a pale cream amorphous solid (25.6 mg, 0.0900 mmol, 46.5 %).

TLC R_f = 0.40 (5 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 3249.3 (N-H), 3065.1 (N-H), 2916.6 (C-H), 2852.6 (C-H), 2728.1 (C-H), 2106.8 (azide), 1634.5 (C=O)

¹H NMR (400 MHz, MeOD) δ / ppm = 7.73 (d, J = 8.6 Hz, 1 H, *ortho* to NH), 7.71 (d, J = 2.8 Hz, 1 H, *ortho* to N₃ and *ortho* to C(=O)), 7.47 (dd, J = 8.9, 2.7 Hz, 1 H, *para* to C(=O)), 6.24 (s, 1 H, C(=O)CH), 2.69 (t, J = 7.7 Hz, 2 H, CCH₂), 1.68 (quin, J = 7.6 Hz, 2 H, CCH₂CH₂), 1.28 - 1.39 (m, 4 H, CCH₂CH₂CH₂CH₂CH₂), 1.18 - 1.28 (m, 4 H, CH₂CH₂CH₃), 0.85 (t, J = 6.8 Hz, 3 H, CH₃)

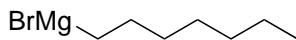
¹³C NMR (101 MHz, MeOD) δ / ppm = 172.3 (C(=O)), 155.5 (NH₂CH₂), 137.4 (CN₃), 135.6 (*para* to N₃), 124.6 (*para* to C(=O)), 124.1 (*ipso* to C(=O)), 120.7 (*meta* to N₃ and *meta* to C(=O)), 112.8 (*ortho* to N₃ and *ortho* to C(=O)), 107.0 (C(=O)CH), 33.3 (NH₂CH₂), 31.2 (CH₂CH₂CH₃), 28.3 - 28.5 (CH₂CH₂CH₂CH₂CH₂CH₃), 22.1 (CH₂CH₃), 14.0 (CH₃)

HRMS (ESI⁺) m/z / Da = 285.1728, [M+H]⁺ found, [C₁₆H₂₁N₄O]⁺ requires 285.1715

Spectroscopic data are not consistent with the literature.¹⁵⁰

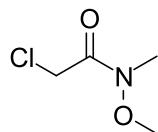
????

5.6 Heptyl magnesium bromide 48



Magnesium turnings (352 mg, 14.5 mmol, 1 eq.) were added to an oven-dried flask under argon. THF (15 ml) was added, followed by bromoheptane **47** (2.40 ml, 14.5 mmol, 1 eq.) dropwise. The mixture was stirred at r.t. for 2 h followed by heating to reflux for 2 h. Heptyl magnesium bromide **48** was obtained as a pale grey suspension (15 ml, ~1 M) which was used without further purification.

5.7 2-Chloro-*N*-methoxy-*N*-methylacetamide 51



N,O-Dimethylhydroxyl amine hydrochloride **49** (6.00 g, 61.5 mmol, 1 eq.) and toluene (75 ml) were added successively to a stirred solution of potassium carbonate (22.4 g, 162 mmol, 2.63 eq.) in water (75 ml) at 0 °C under argon. The mixture was cooled to -5 °C and chloroacetyl chloride **50** (5.88 ml, 73.8 mmol, 1.20 eq.) was added dropwise over 5 min. The mixture was allowed to warm to r.t. over 30 min, then the organic layer was separated and the aqueous layer was extracted with toluene (3×20 ml). The combined organic extracts were dried with MgSO₄ and the solvent was removed by rotary evaporation followed by high vacuum. **51** was obtained as white, prism-like crystals (7.24 g, 52.6 mmol, 71 %).

mp T / $^{\circ}\text{C}$ = 38.8 (toluene)

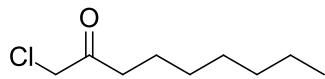
IR (neat) ν_{max} / cm^{-1} = 3016.7 (C-H), 2966.4 (C-H), 2946.7 (C-H), 2827.7 (C-H), 1666.2 (C=O)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 4.20 (s, 2 H, ClCH₂C=O), 3.71 (m, 3 H, OCH₃), 3.18 (s, 3 H, NCH₃)

¹³C NMR (101 MHz, CDCl₃) δ / ppm = 167.4 (C=O), 61.6 (OCH₃), 40.9 (ClCH₂C=O), 32.6 (NCH₃)

Spectroscopic data are consistent with the literature.⁴³

5.8 1-Chlorononan-2-one 52



2-Chloro-*N*-methoxy-*N*-methylacetamide **51** (1.00 g, 7.26 mmol, 1 eq.) was added to a dry flask under argon. THF (20 ml) was added and the flask cooled to 0 °C. Heptyl magnesium bromide **48** (~ 1 M, 15.0 ml, 15.0

mmol, 2.07 eq.) was added dropwise over 5 min, then the mixture was allowed to warm to r.t. and stirred for 15 h. The reaction mixture was then poured into HCl (aq., 2 N, 60 ml) at 0 °C and stirred for 10 min. The mixture was extracted with toluene (30 ml) and the aqueous layer discarded. The organic layer was washed with brine and dried with MgSO₄, and the solvent was removed by rotary evaporation. **52** was obtained as a colourless oil (1.23 g, 6.96 mmol, 96 %).

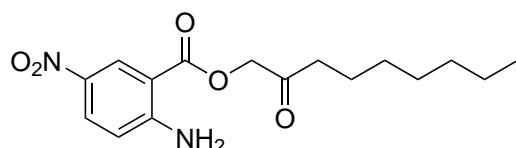
IR (neat) ν_{max} / cm⁻¹ = 2951.7 (C-H), 2925.0 (C-H), 2855.5 (C-H), 1720.4 (C=O)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 4.05 (s, 2 H, ClCH₂C(=O)), 2.54 (t, J = 7.4 Hz, 2 H, C(=O)CH₂CH₂), 1.59 (quin, J = 7.0 Hz, 2 H, C(=O)CH₂CH₂), 1.34 - 1.21 (m, 8 H, CH₂CH₂CH₂CH₂CH₃), 0.87 (t, J = 6.8 Hz, 3 H, CH₃)

¹³C NMR (101 MHz, CDCl₃) δ / ppm = 202.6 (C(=O)), 48.1 (CH₂Cl), 39.6 (C(=O)CH₂CH₂), 31.5 (CH₂CH₂CH₃), 28.9 (CH₂), 28.9 (CH₂), 23.5 (C(=O)CH₂CH₂), 22.5 (CH₂CH₃), 13.9 (CH₃)

Spectroscopic data are consistent with the literature.⁴³

5.9 2-Oxononyl 2-amino-5-nitrobenzoate 54



5-Nitroanthranilic acid **53** (500 mg, 2.75 mmol, 1.38 eq.) and potassium carbonate (270 mg, 2.00 mmol, 1 eq.) were dissolved in DMF (5 ml). The mixture was heated under argon to 90 °C and stirred for 1 h then cooled to r.t.. 1-Chlorononan-2-one **52** (353 mg, 2.00 mmol, 1 eq.) was added and the mixture was stirred for 15 h. The solution was poured into Na₂HCO₃ (aq., 10 %, 50 ml) and ice (~ 20 g). The precipitate was collected by vacuum filtration, washed with water and dried under high vacuum. **54** was obtained as a yellow amorphous solid (0.674 g, 2.00 mmol, 100 %).

mp T / °C = 135 (H₂O)

IR (neat) ν_{max} / cm⁻¹ = 3453.3 (N-H), 3350.5 (N-H), 2924.9 (C-H), 2853.9 (C-H), 1720.1 (ester C=O) 1703.9 (ketone C=O) 1626.1 (N-H bend) 1602.7 (aromatic) 1572.5 (N-O) 1506.6 (N-O)

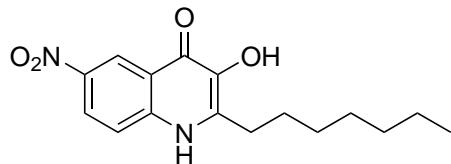
¹H NMR (400 MHz, DMSO-d₆) δ / ppm = 8.66 (d, *J* = 2.8 Hz, 1 H, *ortho* to C(=O)), 8.12 (dd, *J* = 2.8, 9.4 Hz, 1 H, *para* to C(=O)), 6.93 (d, *J* = 9.4 Hz, 1 H, *meta* to C(=O)), 5.05 (s, 2 H, OCCH₂C(=O)), 2.49 (t, *J* = 7.4 Hz, 2 H, C(=O)CH₂CH₂), 1.52 (quin, *J* = 7.2 Hz, 2 H, C(=O)CH₂CH₂), 1.32 - 1.20 (m, 8 H, CH₂CH₂CH₂CH₂CH₃), 0.86 (t, *J* = 6.8 Hz, 3 H, CH₃)

¹³C NMR (101 MHz, DMSO-d₆) δ / ppm = 204.4 (OCH₂C(=O)), 165.6 (C(=O)O), 156.3 (*ipso* to NH₂), 135.7 (*ipso* to NO₂), 129.6 (*para* to C(=O)), 128.9 (*ortho* to C(=O)), 117.4 (*meta* to C(=O)), 107.5 (*ipso* to C(=O)), 68.8 (OCH₂C(=O)), 38.3 (C(=O)CH₂CH₂), 31.6 (CH₂CH₂CH₃), 28.9 (CH₂), 28.9 (CH₂), 23.2 (C(=O)CH₂CH₂), 22.5 (CH₂CH₃), 14.4 (CH₃)

HRMS (ESI⁺) m/z / Da = 323.1610, [M+H]⁺, [C₁₆H₂₃N₂O₅]⁺ requires 323.1607

Spectroscopic data are consistent with the literature.¹⁵⁰

5.10 6-Nitro-2-heptyl-3-hydroxyquinolin-4(1H)-one 55



2-Oxononyl 2-amino-5-nitrobenzoate **54** (100 mg, 0.340 mmol, 1 eq.) and polyphosphoric acid (300 mg) were stirred for 5.5 h at 90 °C under argon. The mixture was then poured into NaHCO₃ (sat., aq., 50 ml) cooled on ice. The precipitate was collected by vacuum filtration, washed with water (50 ml) and dried under high vacuum. **55** was obtained as a yellow-brown amorphous solid (44 mg, 0.145 mmol, 43 %).

mp *T* / °C = 223 (H₂O, EtOAc)

IR (neat) ν_{max} / cm⁻¹ = 3436.0 (N-H), 3000.0 (O-H, br), 2955.4 (C-H), 2925.8 (C-H), 2850.9 (C-H), 1648.2 (C=O), 1570.7 (N-O), 1536.4 (N-O)

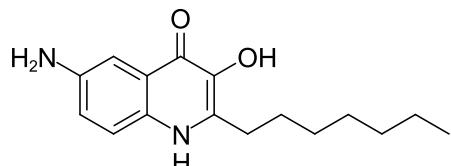
¹H NMR (400 MHz, DMSO-d₆) δ / ppm = 12.00 (s, 1 H, NH), 8.91 (d, *J* = 2.8 Hz, 1 H, *ortho* to C=O), 8.29 (dd, *J* = 2.7, 9.2 Hz, 1 H, *para* to C=O), 7.70 (d, *J* = 9.3 Hz, 1 H, *meta* to C=O), 2.75 (t, *J* = 7.7 Hz, 2 H, CCH₂), 1.67 (quin, *J* = 7.3 Hz, 2 H, CCH₂CH₂), 1.36 - 1.23 (m, 8 H, CH₂CH₂CH₂CH₂CH₃), 0.85 (t, *J* = 7.0 Hz, 3 H, CH₃)

¹³C NMR (101 MHz, DMSO-d₆) δ / ppm = 169.7 (C=O), 141.9 (*para* to NO₂), 140.7 (*ipso* to NO₂), 139.6 (*ipso* to OH), 137.3 (C=COH), 124.3 (*para* to C=O), 122.3 (*ortho* to NO₂ and *ortho* to C=O), 121.5 (*ipso* to C=O), 120.0 (*meta* to NO₂ and *meta* to C=O), 31.6 (CH₂CH₂CH₃), 29.2 (CH₂), 28.9 (CH₂), 28.5 (CCH₂), 28.1 (CCH₂CH₂), 22.5 (CH₂CH₃), 14.4 (CH₃)

HRMS (ESI⁺) *m/z* / Da = 305.1501, [M+H]⁺, [C₁₆H₂₁N₂O₄]⁺ requires 305.1500

Spectroscopic data are consistent with the literature.¹⁵⁰

5.11 6-Amino-2-heptyl-3-hydroxyquinolin-4(1H)-one 56



6-Nitro-2-heptyl-3-hydroxyquinolin-4(1H)-one **55** (20 mg, 0.0658 mmol, 1 eq.) and PtO₂ (2 mg, 10 weight %) were stirred in MeOH (1 ml) under a H₂ atmosphere for 45 min at room temperature and pressure. The reaction mixture was then filtered through celite and the solvent was removed under vacuum. **56** was obtained as a yellow-brown amorphous solid (14.5 mg, 0.0529 mmol, 80 %).

mp (MeOH) T / °C = 176

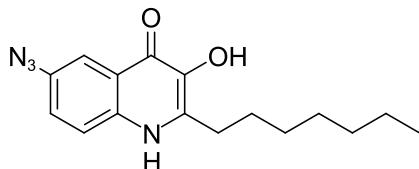
IR (neat) ν_{max} / cm⁻¹ = 3000.00 (O-H, br) 2925.41 (C-H), 2854.09 (C-H), 1613.43 (C=O)

¹H NMR (400 MHz, MeOD) δ / ppm = 11.12 (s, 1 H, NH), 7.47 (d, J = 8.9 Hz, 1 H, *meta* to C=O), 7.40 (d, J = 2.4 Hz, 1 H, *ortho* to C=O), 7.16 (dd, J = 2.6, 9.0 Hz, 1 H, *para* to C=O), 2.86 (t, J = 7.5 Hz, 2 H, CCH₂), 1.75 (quin, J = 7.8 Hz, 2 H, CCH₂CH₂), 1.48 - 1.22 (m, J = 5.4 Hz, 8 H, CH₂CH₂CH₂CH₂CH₃), 0.89 (t, J = 6.7 Hz, 3 H, CH₃)

¹³C NMR (101 MHz, MeOD) δ / ppm = 166.8 (C=O), 144.8 (para to NH₂ or *ipso* to C=O), 140.5 (*ipso* to COH), 138.6 (C=COH), 132.6 (*ipso* to NH₂), 124.8 (para to NH₂ or *ipso* to C=O), 123.8 (para to C=O), 107.7 (*meta* to NH₂ and *meta* to C=O), 106.4 (*ortho* to NH₂ and *ortho* to C=O), 33.0 (CH₂CH₂CH₃), 29.5 - 31.0 (CCH₂CH₂CH₂CH₂), 23.8 (CH₂CH₃), 14.5 (CH₃)

HRMS (ESI⁺) m/z / Da = 275.1760, [M+H]⁺, [C₁₆H₂₃N₂O₂]⁺ requires 275.1762 Spectroscopic data are not consistent with the literature.¹⁵⁰ It is possible that Baker's product is a Zn adduct.

5.12 6-Azido-2-heptyl-3-hydroxyquinolin-4(1H)-one 57



6-Amino-2-heptyl-3-hydroxyquinolin-4(1H)-one **56** (18.2 mg, 0.0664 mmol, 1 eq.) was dissolved in HCl (conc., aq., 0.8 ml) and MeOH (0.5 ml) at 0 °C. NaNO₂ (5.0 mg, 0.0725 mmol, 1.09 eq.) in H₂O (0.2 ml) was added dropwise over 2 min and the mixture was stirred at 0 °C for 50 min, during which time the solution turned from yellow to orange. NaN₃ (4.9 mg, 0.0754 mmol, 1.14 eq.) in H₂O (0.2 ml) was then added and the mixture was allowed to warm to r.t. and stirred for 4 h. The reaction mixture was then filtered and the solid was dried under reduced pressure. **57** was obtained as a brown amorphous solid (5.5 mg, 0.0183 mmol, 28 %).

IR (neat) ν_{max} / cm⁻¹ = pending

don't have?

¹H NMR (400 MHz, DMSO-d₆) δ / ppm = 7.74 (s, 1 H, *ortho* to C=O), 7.65 (d, J = 6.9 Hz, 1 H, *meta* to C=O), 7.32 (d, J = 7.4 Hz, 1 H, *para* to C=O), 2.75 (t, J = 7.5 Hz, 2 H, CCH₂), 1.67 (quin, J = 6.4 Hz, 2 H, CCH₂CH₂), 1.43 - 1.13 (m, 8 H, CH₂CH₂CH₂CH₂CH₃), 0.85 (t, J = 6.8 Hz, 3 H, CH₃)

¹³C NMR (101 MHz, DMSO-d₆) δ / ppm = pending

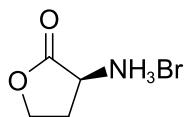
don't have?

HRMS (ESI⁺) m/z / Da = pending, [M+H]⁺, [C₁₆H₂₁N₄O₂]⁺ requires 301.1659

try?

Spectroscopic data are consistent with the literature.¹⁵⁰

5.13 (S)-3-Aminodihydrofuran-2(3H)-one hydrobromide 60



L-Methionine **58** (3.04 g, 20.4 mmol, 1 eq.) and bromoacetic acid **59** (3.08 g, 22.2 mmol, 1.09 eq.) were dissolved in *i*-PrOH (12.5 ml), H₂O (12.5 ml) and AcOH (5 ml). The reaction was refluxed for 15 h then concentrated under vacuum. The resulting brown oil was added to a mixture of *i*-PrOH (16 ml) and HBr (33 % in AcOH, 4 ml), causing the precipitation of a pale pink amorphous solid. The precipitate was collected by filtration and washed with *i*-PrOH (20 ml). The filtrate was concentrated under vacuum and precipitated again using the same procedure. The two crops of precipitate were combined. **60** was obtained as a pale pink amorphous solid (1.73 g, 9.50 mmol, 41 % yield).

mp *T* / °C = 242 (*i*-PrOH/AcOH, gas evolved)

IR (neat) ν_{max} / cm⁻¹ = 2972.1 (N-H), 2877.5 (N-H), 1771.8 (C=O), 1585.1 (N-H bend), 1572.2 (N-H bend)

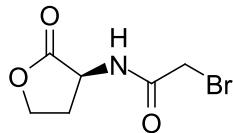
¹H NMR (400 MHz, DMSO-d₆) δ / ppm = 8.59 (br s, 3 H, NH₃⁺), 4.46 (dt, *J* = 1.3, 8.9 Hz, 1 H, OCHH), 4.37 (dd, *J* = 8.8, 11.4 Hz, 1 H, CHNH₃⁺), 4.29 (ddd, *J* = 6.1, 8.8, 10.9 Hz, 1 H, OCHH), 2.57 (dddd, *J* = 1.2, 6.1, 8.9, 12.3 Hz, 1 H, OCH₂CHH), 2.26 (dtd, *J* = 9.0, 11.2, 12.2 Hz, 1 H, OCH₂CHH)

¹³C NMR (101 MHz, DMSO-d₆) δ / ppm = 173.3 (C=O), 66.2 (OCH₂), 47.8 (CHNH₃⁺), 27.0 (OCH₂CH₂)

$[\alpha]_D^{20}$ / °10⁻¹cm²g⁻¹ = -30.0, lit. = -25.0 (*c* / g(100 ml)⁻¹ = 0.0200, DMSO)

The data are consistent with the literature.¹⁶⁰

5.14 (S)-2-Bromo-N-(2-oxotetrahydrofuran-3-yl)acetamide 62



(*S*)-3-Aminodihydrofuran-2(3H)-one hydrobromide **60** (100 mg, 0.549 mmol, 1.08 eq.) and NaHCO₃ (84.9 mg, 1.01 mmol, 2.00 eq.) were dissolved in CH₂Cl₂ (2 ml) and H₂O (2 ml). Bromoacetyl bromide **61** (44.0 μ L, 102 mg, 0.505 mmol, 1.00 eq.) was then added dropwise. The reaction mixture was stirred for 24 h, after which the CH₂Cl₂ was removed under vacuum. The aqueous phase was extracted with EtOAc (4 \times 10 ml). The combined organic layers were dried with MgSO₄ and the solvent was removed under reduced pressure. **62** was obtained as white, needle-like crystals (88.0 mg, 0.396 mmol, 74 %).

mp *T* / °C = 132 (EtOAc)

IR (neat) ν_{max} / cm⁻¹ = 3255.7 (N-H), 3066.6 (C-H), 1763.0 (lactone C=O), 1658.0 (amide C=O), 1552.7 (N-H bend)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 6.94 (br s, 1 H, NH), 4.57 (ddd, J = 11.7, 8.6, 5.9 Hz, 1 H, CHNH), 4.51 (td, J = 9.2, 1.0 Hz, 1 H, OCHH), 4.32 (ddd, J = 11.3, 9.4, 5.9 Hz, 1 H, OCHH), 3.93 (s, 1 H, CHHBr), 3.93 (s, 1 H, CHHBr), 2.87 (dddd, J = 12.6, 8.6, 5.9, 1.3 Hz, 1 H, OCH₂CHH), 2.22 (dtd, J = 12.6, 11.5, 11.5, 8.9 Hz, 1 H, OCH₂CHH)

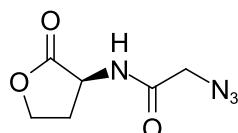
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 174.6 (OC=O), 166.4 (C=O)NH), 66.1 (OCH₂), 49.8 (CHNHC=O), 29.9 (OCH₂CH₂), 28.2 (O=CCH₂Br)

HRMS The compound does not ionise.

$[\alpha]_D^{20}$ / ${}^{\circ}10^{-1}\text{cm}^2\text{g}^{-1}$ = 27.0, lit. = 20.5 (c / g(100 ml) $^{-1}$ = 0.00740, CHCl₃)

The data are consistent with the literature.^{160,178}

5.15 (S)-2-Azido-N-(2-oxotetrahydrofuran-3-yl)acetamide 63



(3*S*)-2-Oxotetrahydrofuran-3-aminium bromide **60** (100 mg, 0.552 mmol, 1.08 eq.), NaN₃ (85.7 mg, 1.32 mmol, 2.61 eq.) and NaHCO₃ (84.9 mg, 1.01 mmol, 2.00 eq.) were dissolved in CH₂Cl₂ (2 ml) and H₂O (2 ml). Bromoacetyl bromide **61** (44.0 μ L, 102 mg, 0.505 mmol, 1.00 eq.) was then added dropwise. The reaction mixture was stirred for 48 h, after which the CH₂Cl₂ was removed under vacuum. The aqueous phase was extracted with EtOAc (4 \times 10 ml). The combined organic layers were dried with MgSO₄ and the solvent was removed under reduced pressure. **63** was obtained as white, needle-like crystals (38.4 mg, 0.209 mmol, 41 %).

mp T / ${}^{\circ}\text{C}$ = 87 (EtOAc)

IR (neat) ν_{max} / cm⁻¹ = 3283.5 (N-H), 2923.3 (C-H), 2853.0 (C-H), 2129.7 (N₃), 1782.9 (lactone C=O), 1661.4 (amide C=O), 1536.8 (N-H bend)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 7.05 (br d, J = 6.5 Hz, 1 H, NH), 4.64 (ddd, J = 11.6, 8.7, 6.8 Hz, 1 H, CHNH), 4.48 (td, J = 9.1, 1.3 Hz, 1 H, OCHH), 4.30 (ddd, J = 11.2, 9.2, 6.0 Hz, 1 H, OCHH), 4.04 (s, 2 H, CH₂N₃), 2.76 (dddd, J = 12.5, 8.8, 6.0, 1.4 Hz, 1 H, OCH₂CHH), 2.25 (dtd, J = 12.5, 11.4, 11.4, 8.9 Hz, 1 H, OCH₂CHH)

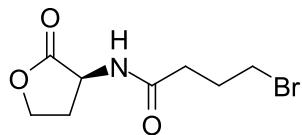
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 174.9 (OC=O), 167.5 (C=ONH), 66.0 (OCH₂), 52.2 (O=CCH₂N₃), 48.9 (CHNHC=O), 29.7 (OCH₂CH₂)

HRMS The compound does not ionise.

$[\alpha]_D^{20}$ / ${}^{\circ}10^{-1}\text{cm}^2\text{g}^{-1}$ = -32.6, lit. = -24.4 (c / g(100 ml) $^{-1}$ = 0.0430, DMSO)

The data are consistent with the literature.¹⁶⁰

5.16 (*S*)-4-Bromo-*N*-(2-oxotetrahydrofuran-3-yl)butanamide 65



(*S*)-3-Aminodihydrofuran-2(*3H*)-one hydrobromide **60** (200 mg, 1.10 mmol, 1.00 eq.) and NaHCO₃ (170 mg, 2.02 mmol, 1.84 eq.) were dissolved in CH₂Cl₂ (2 ml) and H₂O (2 ml). Bromobutyryl chloride **64** (140 μ L, 224 mg, 1.21 mmol, 1.10 eq.) was then added dropwise. The reaction mixture was stirred for 1 h, after which the CH₂Cl₂ was removed under vacuum. The aqueous phase was extracted with EtOAc (7×5 ml) and the combined organic layers were dried with MgSO₄. The solvent was removed under vacuum to give white crystals which were recrystallised from EtOAc. **65** was obtained as white, needle-like crystals (219 mg, 0.878 mmol, 80 %).

mp *T* / °C = 105 (EtOAc)

IR (neat) ν_{max} / cm⁻¹ = 3307.9 (N-H), 3073.9 (C-H), 2948.9 (C-H), 1773.7 (lactone C=O), 1643.5 (amide C=O), 1541.4 (N-H bend)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 6.31 (br d, *J* = 5.5 Hz, 1 H, NH), 4.59 (ddd, *J* = 6.2, 8.7, 11.5 Hz, 1 H, CHNH), 4.48 (dt, *J* = 1.2, 8.9 Hz, 1 H, OCHH), 4.30 (ddd, *J* = 5.8, 9.3, 11.3 Hz, 1 H, OCHH), 3.49 (t, *J* = 6.3 Hz, 2 H, CH₂Br), 2.82 (dddd, *J* = 1.3, 5.9, 8.7, 12.5 Hz, 1 H, OCH₂CHH), 2.47 (t, *J* = 7.3 Hz, 2 H, C(=O)CH₂), 2.26 - 2.15 (m, 3 H, OCH₂CHH and CH₂CH₂Br)

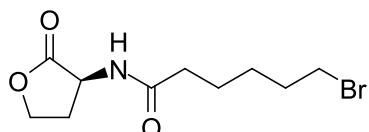
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 175.4 (OC=O), 172.3 (C(=O)NH), 66.1 (OCH₂), 49.3 (CHNHC=O), 33.9 (C(=O)CH₂), 33.1 (CH₂Br), 30.3 (OCH₂CH₂), 27.9 (C(=O)CH₂CH₂)

HRMS The compound does not ionise.

$[\alpha]_D^{26.6}$ / °10⁻¹cm²g⁻¹ = -78 (*c* / g(100 ml)⁻¹ = 0.0833, MeOH)

The compound has not been reported previously.

5.17 (*S*)-6-Bromo-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide 68



(*S*)-3-Aminodihydrofuran-2(*3H*)-one hydrobromide **60** (100 mg, 0.549 mmol, 1.00 eq.) and NaHCO₃ (84.9 mg, 1.01 mmol, 1.84 eq.) were dissolved in CH₂Cl₂ (2 ml) and H₂O (2 ml) at r.t.. Bromohexanoyl chloride **67** (93.0 μ L, 130 mg, 0.608 mmol, 1.11 eq.) was then added dropwise. The reaction mixture was stirred for 4 h, after which the CH₂Cl₂ was removed under vacuum. The mixture was then filtered, washed with H₂O (10 ml) and dried under high vacuum. **68** was obtained as white, needle-like crystals (101 mg, 0.362 mmol, 66 %).

mp *T* / °C = 106 (CH₂Cl₂/H₂O)

IR (neat) ν_{max} / cm^{-1} = 3300.3 (N-H), 3067.6 (C-H), 2937.4 (C-H), 2856.7 (C-H), 1784.8 (lactone C=O), 1639.3 (amide C=O), 1539.9 (N-H bend)

$^1\text{H NMR}$ (400 MHz, CDCl_3) δ / ppm = 6.09 (br d, J = 5.7 Hz, 1 H, NH), 4.57 (ddd, J = 5.9, 8.6, 11.6 Hz, 1 H, CHNH), 4.50 (dt, J = 1.3, 9.1 Hz, 1 H, OCHH), 4.31 (ddd, J = 5.9, 9.3, 11.3 Hz, 1 H, OCHH), 3.43 (t, J = 6.7 Hz, 2 H, CH_2Br), 2.88 (dddd, J = 1.3, 5.9, 8.6, 12.6 Hz, 1 H, OCH_2CHH), 2.30 (dt, J = 1.8, 7.5 Hz, 2 H, C(=O)CH₂), 2.16 (tdt, J = 8.9, 11.5, 12.5 Hz, 1 H, OCH_2CHH), 1.90 (quin, J = 7.2 Hz, 2 H, $\text{CH}_2\text{CH}_2\text{Br}$), 1.71 (quin, J = 7.6 Hz, 2 H, C(=O)CH₂CH₂), 1.59 - 1.46 (m, 2 H, C(=O)CH₂CH₂CH₂)

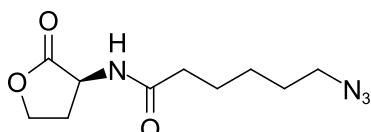
$^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ / ppm = 175.5 (OC=O), 173.3 (C(=O)NH), 66.1 (OCH₂), 49.3 (CHNHC=O), 35.8 (CH₂Br), 33.5 (C(=O)CH₂), 32.3 (CH₂CH₂Br), 30.5 (OCH₂CH₂), 27.6 (C(=O)CH₂CH₂), 24.4 (C(=O)CH₂CH₂CH₂)

HRMS (ESI⁺) m/z / Da = 278.0381, [M+H]⁺, [C₁₀H₁₇BrNO₃]⁺ requires 278.0386

$[\alpha]_D^{26.6}$ / ${}^\circ 10^{-1}\text{cm}^2\text{g}^{-1}$ = -16 (c / g(100 ml)⁻¹ = 0.208, MeOH)

The compound has not been reported previously.

5.18 (*S*)-6-Azido-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide 69



(*S*)-6-Bromo-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide **68** (80 mg, 0.320 mmol, 1.00 eq.) and NaN_3 (26.3 mg, 0.405 mmol, 1.27 eq.) were heated in DMF (0.5 ml) for 5 h at 100 °C. The reaction mixture was then partitioned between CH_2Cl_2 (5 ml) and H_2O (5 ml). The aqueous phase was extracted twice more with CH_2Cl_2 (2×5 ml) and the organic layers were combined and dried over MgSO_4 . The solvent was removed by rotary evaporation followed by high vacuum. **69** was obtained as white, needle-like crystals (42.7 mg, 0.178 mmol, 56 %).

mp T / °C = 90.0 (CH_2Cl_2)

IR (neat) ν_{max} / cm^{-1} = 3314.0 (N-H), 2931.6 (C-H), 2862.9 (C-H), 2095.1 (N₃), 1775.4 (lactone C=O), 1643.1 (amide C=O), 1547.9 (N-H bend)

$^1\text{H NMR}$ (400 MHz, CDCl_3) δ / ppm = 5.96 (d, J = 4.2 Hz, 1 H, NH), 4.54 (ddd, J = 11.7, 8.6, 5.7 Hz, 1 H, CHNH), 4.49 (td, J = 9.1, 1.0 Hz, 1 H, OCHH), 4.30 (ddd, J = 11.3, 9.4, 5.8 Hz, 1 H, OCHH), 3.29 (t, J = 6.9 Hz, 2 H, CH_2N_3), 2.88 (dddd, J = 12.5, 8.6, 5.8, 1.1 Hz, 1 H, OCH_2CHH), 2.28 (t, J = 7.5 Hz, 1 H, C(=O)CHH), 2.28 (t, J = 7.4 Hz, 1 H, C(=O)CHH), 2.14 (tdt, J = 12.3, 11.5, 11.5, 8.8 Hz, 1 H, OCH_2CHH), 1.70 (quin, J = 7.6 Hz, 2 H, $\text{CH}_2\text{CH}_2\text{N}_3$), 1.63 (quin, J = 7.2 Hz, 2 H, C(=O)CH₂CH₂), 1.38 - 1.49 (m, 2 H, C(=O)CH₂CH₂CH₂)

$^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ / ppm = 175.4 (OC=O), 172.2 (C(=O)NH), 66.1 (OCH₂), 51.2 (CH₂N₃), 49.4 (CHNHC=O), 35.9 (C(=O)CH₂), 30.7 (OCH₂CH₂), 28.6 (CH₂CH₂N₃), 26.3 (C(=O)CH₂CH₂), 24.8 (C(=O)CH₂CH₂CH₂)

HRMS (ESI⁺) m/z / Da = 241.1289, [M+H]⁺, [C₁₀H₁₇N₄O₃]⁺ requires 241.1295

$[\alpha]_D^{26.6} / {}^\circ 10^{-1} \text{cm}^2 \text{g}^{-1} = -16$ ($c / \text{g(100 ml)}^{-1} = 0.208$, MeOH)

The compound has not been reported previously.

5.19 Hex-5-ynal 71



Pyridinium chlorochromate (14.6 g, 68.1 mmol, 1.50 eq) and DCM (500 ml) were stirred at r.t. under argon. 5-Hexyn-1-ol **70** (5.00 ml, 45.4 mmol, 1 eq.) was added and the reaction mixture was stirred for 5 h followed by addition of Et₂O (125 ml) and silica gel (62.5 g). The suspension was stirred for 1 h then filtered through a pad of silica (100 g) and washed with Et₂O. The solvent was removed by rotary evaporation. **71** was obtained as a pale yellow-green oil (4.72 g, 49.1 mmol, 72 %).

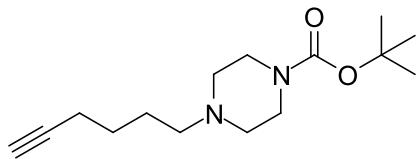
IR (neat) $\nu_{max} / \text{cm}^{-1} = 3292.7$ (alkyne C-H), 2943.3 (alkane C-H), 2830.9 (aldehyde C-H), 2728.6 (aldehyde C-H), 1720.3 (aldehyde C=O)

¹H NMR (400 MHz, CDCl₃) $\delta / \text{ppm} = 9.80$ (s, 1 H, C(=O)H), 2.60 (t, $J = 7.1$ Hz, 2 H, CH₂C(=O)H), 2.26 (dt, $J = 2.6, 6.8$ Hz, 2 H, HC≡CCH₂), 1.98 (t, $J = 2.7$ Hz, 1 H, HC≡C), 1.85 (quin, $J = 7.0$ Hz, 2 H, HC≡CCH₂CH₂)

¹³C NMR (101 MHz, CDCl₃) $\delta / \text{ppm} = 201.6$ (C(=O)), 83.1 (HC≡C), 69.3 (HC≡C), 42.4 (CH₂C(=O)), 20.7 (CH₂CH₂C(=O)), 17.6 (HC≡CCH₂)

Spectroscopic data are consistent with the literature.¹⁶²

5.20 *tert*-Butyl 4-(hex-5-yn-1-yl)piperazine-1-carboxylate 73



Hex-5-ynal **71** (0.407 g, 4.24 mmol, 1.00 eq.) and *tert*-butyl piperazine-1-carboxylate **72** (0.791 g, 4.24 mmol, 1.00 eq.) were stirred under a N₂ atmosphere in 1,2-dichloroethane (20 ml) for 2.5 h followed by addition of sodium triacetoxyborohydride (6.25 g, 29.5 mmol, 7 eq.) in four portions over 4 d. The mixture was stirred for a further day then NaHCO₃ (sat., aq., 120 ml) was added and the product extracted with EtOAc (2×100 ml). The solvent was dried over MgSO₄ and removed by rotary evaporation. **73** was obtained as a colourless liquid (1.12 g, 4.21 mmol, 99 %).

TLC R_f (10 % MeOH/CH₂Cl₂) = 0.55

IR (neat) $\nu_{max} / \text{cm}^{-1} = 3303.6$ (alkyne C-H), 2940.0 (alkane C-H), 2865.2 (C-H), 2810.4 (C-H), 1691.3

(carbamate C=O)

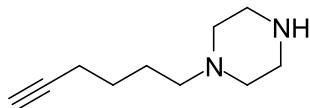
¹H NMR (400 MHz, CDCl₃) δ / ppm = 3.44 (t, J = 5.2 Hz, 4 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.39 (t, J = 5.1 Hz, 4 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂), 2.37 (t, J = 7.3 Hz, 2 H, CH₂CH₂CH₂N), 2.23 (dt, J = 2.7, 6.8 Hz, 2 H, HC≡CCH₂), 1.96 (t, J = 2.7 Hz, 1 H, HC≡C), 1.65 - 1.53 (m, 4 H, HC≡CCH₂CH₂CH₂), 1.47 (s, 9 H, CH₃)

¹³C NMR (101 MHz, CDCl₃) δ / ppm = 154.7 (NC(=O)O), 84.2 (HC≡C), 79.6 (C(CH₃)₃), 68.5 (HC≡C), 60.4 (CH₂CH₂CH₂N), 58.0 (CH₂CH₂CH₂N(CH₂)CH₂), 53.0 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 28.4 (C(CH₃)₃), 26.3 (CH₂CH₂N), 25.7 (HC≡CCH₂CH₂), 18.3 (HC≡CCH₂)

HRMS (ESI⁺) m/z / Da = 267.2073, [M+H]⁺, [C₁₅H₂₇N₂O₂]⁺ requires 267.2064

The compound has not been reported previously.

5.21 1-(Hex-5-yn-1-yl)piperazine 74



tert-Butyl 4-(hex-5-yn-1-yl)piperazine-1-carboxylate **73** (763 mg, 2.86 mmol) was stirred in TFA (10 ml) at r.t. for 2 h. The TFA was removed under vacuum followed by co-evaporation with CH₂Cl₂ (2×20 ml). The oil was diluted with H₂O (10 ml) and the pH adjusted to 14 with NaOH (10 % aq.). This mixture was extracted with CH₂Cl₂ (2×20 ml) and the combined organic layers were dried over MgSO₄. The solvent was removed under vacuum and purified by column chromatography (SiO₂ MeOH/CH₂Cl₂ 3:7). **74** was obtained as a colourless liquid (476 mg, 2.86 mmol, 100 %).

TLC R_f (30 % MeOH/CH₂Cl₂) = 0.20

IR (neat) ν_{max} / cm⁻¹ = 3295.9 (alkyne C-H), 2941.1 (alkane C-H), 2810.6 (alkane C-H), 1637.2 (N-H bend)

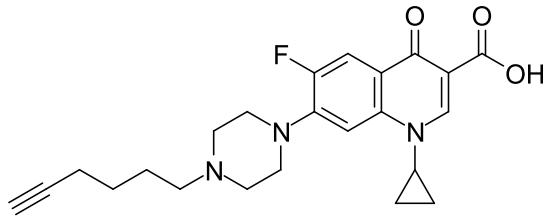
¹H NMR (400 MHz, CDCl₃) δ / ppm = 2.88 (t, J = 4.9 Hz, 4 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.39 (m, 4 H, CH₂CH₂CH₂N(CH₂)CH₂), 2.31 (t, J = 7.1 Hz, 2 H, HC≡CCH₂CH₂CH₂N), 2.20 (dt, J = 2.7, 6.8 Hz, 2 H, HC≡CCH₂), 2.05 (br s, 1 H, NH), 1.93 (t, J = 2.7 Hz, 1 H, HC≡C), 1.65 - 1.48 (m, 4 H, HC≡CCH₂CH₂CH₂N)

¹³C NMR (101 MHz, CDCl₃) δ / ppm = 84.3 (HC≡C), 68.4 (HC≡C), 58.6 (CH₂CH₂CH₂N), 54.5 (CH₂CH₂CH₂N(CH₂)CH₂), 46.0 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 26.4 (CH₂CH₂CH₂N), 25.7 (HC≡CCH₂CH₂), 18.3 (HC≡CCH₂)

HRMS (ESI⁺) m/z / Da = 167.1548, [M+H]⁺, [C₁₀H₁₉N₂]⁺ requires 167.1548

The compound has not been reported previously.

5.22 1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydro-quinoline-3-carboxylic acid 76



7-Chloro-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquino-line-3-carboxylic acid **75** (1.27 g, 4.51 mmol, 1 eq.), 1-(hex-5-yn-1-yl)piperazine **74** (1.5 g, 9.02 mmol, 2 eq.) and *N*-methyl-2-pyrrolidone (10 ml) were stirred in a microwave reactor at 115 °C for 24 h. The reaction mixture was cooled to r.t. and water (80 ml) was added. The mixture was stirred for 3 h and then filtered, and residue was washed with MeOH (50 ml). The resulting solid (0.571 g) was further purified by recrystallisation from EtOAc (50 ml). **76** was obtained as off-white crystals (0.219 g, 0.531 mmol, 11.8 %).

TLC R_f = 0.02 (10 % MeOH/CH₂Cl₂)

mp T / °C = 220 (MeOH, decomposes)

IR (neat) ν_{max} / cm⁻¹ = 3212.0 (alkyne C-H), 2459.3 (O-H), 1722.6 (carboxylic acid C=O), 1626.8 (quinolone C=O)

¹H NMR (500 MHz, DMSO-d₆) δ / ppm = 15.12 (br s, 1 H, C(=O)OH), 8.69 (s, 1 H, *ortho* to C(=O)OH), 7.96 (d, J = 13.0 Hz, 1 H, *ortho* to F), 7.61 (d, J = 7.6 Hz, 1 H, *meta* to F), 3.82 - 3.92 (m, 3 H, NCH(CH₂)₂) and CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 3.54 - 3.68 (br m, 2 H, CH₂CH₂CH₂N(CH₂)CH₂), 3.45 (br. t, J = 11.6 Hz, 2 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 3.21 - 3.29 (br m, 2 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 3.11 - 3.20 (br m, 2 H, CH₂CH₂CH₂N(CH₂)CH₂), 2.84 (t, J = 2.7 Hz, 1 H, HC≡C), 2.24 (td, J = 7.0, 2.7 Hz, 2 H, HC≡CCH₂), 1.83 (br. quin, J = 7.5 Hz, 2 H, HC≡CCH₂CH₂CH₂), 1.52 (quin, J = 7.4 Hz, 2 H, HC≡CCH₂CH₂), 1.29 - 1.36 (m, 2 H, NCH(CHH)₂), 1.16 - 1.23 (m, 2 H, NCH(CHH)₂)

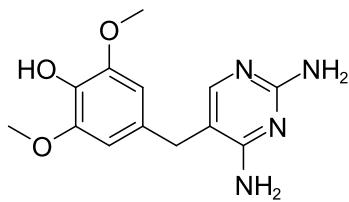
¹³C NMR (126 MHz, DMSO-d₆) δ / ppm = 176.4 (C(=O)CC(=O)OH), 165.8 (C(=O)OH), 152.8 (d, J = 248.5 Hz, *ipso* to F), 148.2 (CHCC(=O)OH), 143.7 (d, J = 11.1 Hz, *para* to C(=O)), 139.1 (*para* to F), 119.4 (d, J = 6.9 Hz, *ipso* to C(=O)), 111.2 (d, J = 22.5 Hz, *ortho* to F and *ortho* to C(=O)), 106.9 (*meta* to F and *meta* to C(=O)), 106.9 (C(=O)CC(=O)OH), 83.9 (HC≡C), 71.8 (HC≡C), 55.0 (CH₂CH₂N(CH₂)₂), 50.5 (CH₂CH₂CH₂N(CH₂)CH₂), 46.3 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 36.0 (NCH(CH₂)₂), 25.2 (HC≡CCH₂CH₂), 22.3 (HC≡CCH₂CH₂CH₂), 17.4 (HC≡CCH₂), 7.6 (NCH(CH₂)₂)

¹⁹F NMR (376.45 MHz, MeOD) δ / ppm = -121.8 (s, ciprofloxacin F)

HRMS (ESI⁺) m/z / Da = 412.2036, [M+H]⁺, [C₂₃H₂₇N₃O₃F]⁺ requires 412.2030

The compound has not been reported previously.

5.23 4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenol 77



Hydrobromic acid (48 % w/w, aq., 50 ml) was heated to 100 °C. Trimethoprim **25** (5.00 g, 17.2 mmol) was added, and the suspension was stirred for 40 min under Ar. The mixture was removed from the heat, and NaOH (50 % w/w, aq., 15 ml) was added dropwise. The reaction mixture was then cooled slowly to 0 °C, and the resulting crystals were filtered out and washed with cold water. The crystals were then dissolved in hot water (80 ml), neutralized with NH₄OH (sat., aq.) and cooled slowly to 0 °C. The resulting crystals were filtered out, washed with cold water and dried under vacuum. **77** was obtained as pale pink prisms (2.06 g, 7.46 mmol, 43.4 %).

TLC R_f = 0.04 (5 % MeOH/CHCl₂)

mp T / °C = 238 (H₂O, decomposes)

IR (neat) ν_{max} / cm⁻¹ = 3314.0 (N-H), 3137.4 (N-H), 3045.3 (C-H), 3000.9 (C-H), 2938.1 (C-H), 2838.7 (C-H), 1662.9 (pyrimidine), 1645.2 (pyrimidine), 1626.6 (pyrimidine)

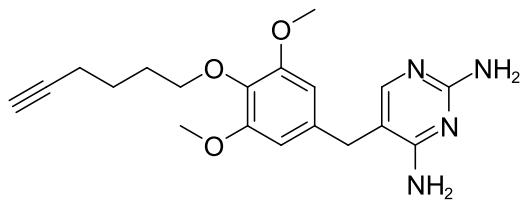
¹H NMR (400 MHz, MeOD) δ / ppm = 7.21 (s, 1 H, CHN), 6.54 (s, 2 H, *meta* to OCH₂), 4.87 (br s, 5 H, OH, NH₂ × 2), 3.82 (s, 6 H, OCH₃), 3.63 (s, 2 H, CCH₂C)

¹³C NMR (101 MHz, MeOD) δ / ppm = 166.4 (CH₂CCNH₂), 162.0 (CHNCNH₂), 156.2 (CHNCNH₂), 149.8 (*ipso* to OCH₃), 135.9 (*ipso* to OH), 128.2 (*para* to OH), 111.7 (CH₂CCNH₂), 107.5 (*meta* to OH), 57.0 (OCH₃), 33.9 (CCH₂C)

HRMS (ESI⁺) m/z / Da = 277.1295, [M+H]⁺ found, [C₁₃H₁₇N₄O₃]⁺ requires 277.1301

The data are consistent with the literature.¹⁵²

5.24 5-(4-(Hex-5-yn-1-yloxy)-3,5-dimethoxybenzyl)pyrimidine-2,4-diamine 79



4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenol **77** (1.00 g, 3.62 mmol, 1 eq.), 6-chloro-1-hexyne **78** (0.524 ml, 0.420 g, 4.34 mmol, 1.2 eq.), Cs₂CO₃ (2.36 g, 7.24 mmol, 2 eq.) and anhydrous DMF (30 ml) were stirred at 70 °C for 7 h. The solvent was removed under reduced pressure, then CH₂Cl₂ (30 ml) was

added and the mixture filtered. The filtrate was concentrated under reduced pressure and purified by column chromatography using a Combiflash (SiO_2 , 5 % MeOH/CH₂Cl₂). **79** was obtained as a pale cream amorphous solid (0.327 g, 0.917 mmol, 25.3 %).

TLC R_f = 0.14 (5 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 3451.4 (alkyne C-H), 3313.4 (N-H), 3136.7 (N-H), 3113.9 (N-H), 2944.2 (C-H), 2839.0 (C-H), 1635.1 (pyrimidine)

¹H NMR (400 MHz, MeOD) δ / ppm = 7.77 (s, 1 H, CHN), 6.37 (s, 2 H, *meta* to OCH₂), 4.83 (br s, 2 H, CHNCNH₂), 4.63 (br s, 2 H, CH₂CCNH₂), 3.95 (t, J = 6.3 Hz, 2 H, CH₂O), 3.79 (s, 6 H, OCH₃), 3.65 (s, 2 H, CCH₂C), 2.28 (td, J = 7.1, 2.6 Hz, 2 H, HC≡CCH₂), 1.94 (t, J = 2.7 Hz, 1 H, HC≡C), 1.81 - 1.90 (m, 2 H, CH₂CH₂O), 1.71 - 1.80 (m, 2 H, CH₂CH₂CH₂O)

¹³C NMR (101 MHz, MeOD) δ / ppm = 162.7 (CH₂CCNH₂), 162.0 (CHNCNH₂), 156.4 (CHNCNH₂), 153.8 (*ipso* to OCH₃), 136.0 (*ipso* to OCH₂), 133.6 (*para* to OCH₂), 106.5 (CH₂CCNH₂), 105.0 (*meta* to OCH₂), 84.5 (HC≡C), 72.6 (CH₂O), 68.3 (HC≡C), 56.1 (OCH₃), 34.7 (CCH₂C), 29.1 (CH₂CH₂O), 24.9 (CH₂CH₂CH₂O), 18.0 (HC≡CCH₂)

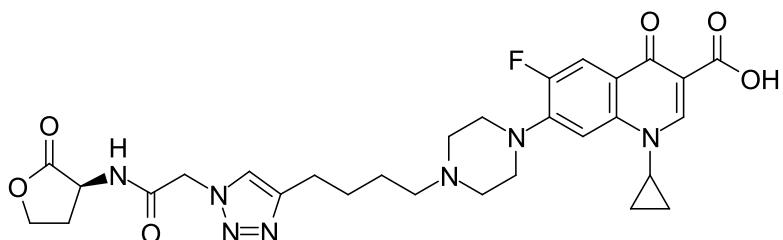
HRMS (ESI⁺) m/z / Da = 357.1920, [M+H]⁺ found, [C₁₉H₂₅N₄O₃]⁺ requires 357.1927

The compound has not been reported previously.

5.25 Optimised general procedure for the click reaction

Azide (1 eq.) and alkyne (1 eq.) were dissolved in 50 % *t*-BuOH/water in a round-bottomed flask with a stirrer bar, closed with a new septum. The mixture was degassed by bubbling through N₂. The mixture was placed under positive pressure of Ar using a balloon. Equimolar amounts of CuSO₄ · 5 H₂O and THPTA **82** were dissolved in water to make a 50 mM solution and similarly degassed. Sodium ascorbate was dissolved in water to make a 100 mM solution and similarly degassed. The Cu/THPTA solution (0.05 eq.) was added to the reaction mixture, followed by the sodium ascorbate solution (0.1 eq.). The mixture was stirred for 2 h and monitored using LCMS. HL derivative conjugates were dry-loaded onto SiO₂ and purified by column chromatography (SiO₂, 0-20 % MeOH/CH₂Cl₂). Other conjugates were purified by preparative HPLC (5-95 % acetonitrile (0.1 % TFA)/water (0.05 % TFA) over 20 min).

5.26 (*S*)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(2-oxo-2-((2-oxotetrahydrofuran-3-yl)amino)ethyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid **80**



50 % water/*t*-BuOH (2 ml) was degassed by bubbling N₂ through it. This was then added to a mixture of 1-cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **76** (20.6 mg, 50.0 μ mol, 1 eq.) and (*S*)-2-azido-*N*-(2-oxotetrahydrofuran-3-yl)acetamide **63** (9.2 mg, 50.0 μ mol, 1 eq.). A similarly degassed solution of CuSO₄ · 5 H₂O (624 μ g, 2.5 μ mol, 0.05 eq. 50 mM), THPTA (1.09 mg, 2.5 μ mol, 0.05 eq. 50 mM) and sodium ascorbate (991 μ g, 5 μ mol, 0.1 eq., 100 mM) in 50 % water/*t*-BuOH (50 μ l) was then added. The mixture was stirred at r.t. under argon for 3 h. On observation that the reaction had stalled, the reaction was degassed again, and a further portion of catalyst solution (50 μ l) was added. After a further 3 h the reaction mixture was dry-loaded onto SiO₂ and purified by column chromatography using a Combiflash (SiO₂, 0-20 % MeOH/CH₂Cl₂ over 15 min). The combined pure fractions were dried with MgSO₄ and evaporated under reduced pressure. **80** was obtained as a white amorphous solid (8.8 mg, 14.8 μ mol, 29.6 %).

IR (neat) ν_{max} / cm⁻¹ = 3266.3 (N-H), 2949.0 (C-H), 2934.8 (C-H), 2827.2 (C-H), 1778.0 (lactone C=O), 1724.9 (carboxylic acid C=O), 1665.0 (amide C=O), 1625.5 (quinolone C=O)

¹H NMR (400 MHz, DMSO d₆) δ / ppm = 15.23 (s, 1 H, C(=O)OH), 8.84 (d, *J* = 7.9 Hz, 1 H, NH), 8.66 (s, 1 H, *ortho* to C(=O)OH), 7.90 (d, *J* = 13.3 Hz, 1 H, *ortho* to F), 7.82 (s, 1 H, CH=CH₂), 7.57 (d, *J* = 7.6 Hz, 1 H, *meta* to F), 5.13 (s, 1 H, C(=O)CH₂HN), 5.12 (s, 1 H, C(=O)CH₂N), 4.64 (ddd, *J* = 10.9, 9.0, 7.8 Hz, 1 H, CH₂HN), 4.36 (td, *J* = 8.9, 1.7 Hz, 1 H, OCH₂H), 4.23 (ddd, *J* = 10.6, 8.8, 6.4 Hz, 1 H, OCH₂H), 3.83 (tt, *J* = 7.0, 4.0 Hz, 1 H, NCH₂(CH₂)₂), 3.32 (br s, 4 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.67 (t, *J* = 7.4 Hz, 2 H, CH=CH₂), 2.58 (br t, *J* = 5.0 Hz, 4 H, CH₂CH₂CH₂N(CH₂)CH₂), 2.42 - 2.49 (m, 1 H, OCH₂CH₂H), 2.40 (t, *J* = 7.1 Hz, 2 H, CH=CH₂CH₂CH₂CH₂), 2.17 (dtd, *J* = 11.7, 10.8, 9.0 Hz, 1 H, OCH₂CH₂H), 1.66 (quin, *J* = 7.2 Hz, 2 H, CH=CH₂CH₂CH₂), 1.53 (quin, *J* = 7.2 Hz, 2 H, CH=CH₂CH₂CH₂), 1.28 - 1.35 (m, 2 H, NCH₂CH₂H), 1.16 - 1.21 (m, 2 H, NCH₂CH₂H)

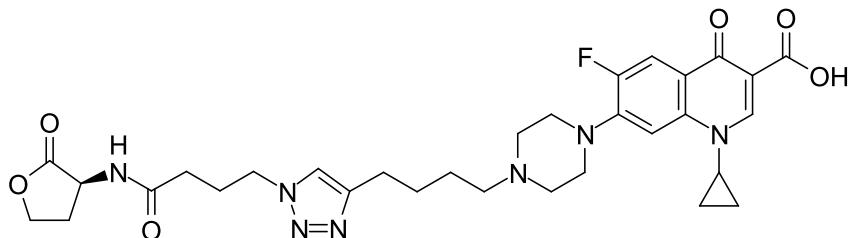
¹³C NMR (101 MHz, DMSO d₆) δ / ppm = 176.4 (C(=O)CC(=O)OH), 174.9 (OC(=O)), 166.0 (C(=O)OH), 165.9 (NHC(=O)), 153.1 (d, *J* = 250.8 Hz, *ipso* to F), 148.0 (CH=CC(=O)OH), 146.6 (CH=CH₂), 145.3 (d, *J* = 9.6 Hz, *ipso* to piperazine), 139.2 (*para* to F), 123.4 (CH=CH₂), 118.5 (d, *J* = 7.5 Hz, *para* to piperazine), 110.9 (d, *J* = 23.5 Hz, *ortho* to C=O and *ortho* to F), 106.7 (CC(=O)OH), 106.4 (d, *J* = 3.2 Hz, *meta* to C=O and *meta* to F), 65.4 (OCH₂), 57.3 (CH=CH₂CH₂CH₂CH₂N), 52.4 (CH₂CH₂CH₂N(CH₂)CH₂), 51.2 (C(=O)CH₂N), 49.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 49.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 48.2 (CH₂HN), 35.9 (NCH₂CH₂H), 28.2 (CH₂CH₂HN), 26.8 (CH=CH₂CH₂CH₂), 25.7 (CH=CH₂CH₂CH₂CH₂), 24.9 (CH=CH₂CH₂CH₂), 7.6 (NCH₂CH₂H)

HRMS (ESI⁺) *m/z* / Da = 596.2627, [M+H]⁺ found, [C₂₉H₃₅FN₇O₆]⁺ requires 596.2633

$[\alpha]_D^{20}$ / °10⁻¹cm²g⁻¹ = -3.5 (*c* / g(100 ml)⁻¹ = 0.0575, MeOH)

The compound has not been reported previously.

5.27 (*S*)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(4-oxo-4-((2-oxotetrahydrofuran-3-yl)amino)butyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid **85**



50 % water/*t*-BuOH (2 ml) was degassed by bubbling N₂ through it. This was then added to a mixture of 1-cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **76** (20.6 mg, 50.0 μ mol, 1 eq.) and (*S*)-4-azido-*N*-(2-oxotetrahydrofuran-3-yl)butanamide **66** (10.6 mg, 50.0 μ mol, 1 eq.). A similarly degassed solution of CuSO₄ · 5 H₂O (624 μ g, 2.5 μ mol, 0.05 eq. 50 mM), THPTA (1.09 mg, 2.5 μ mol, 0.05 eq. 50 mM) and sodium ascorbate (991 μ g, 5 μ mol, 0.1 eq., 100 mM) in 50 % water/*t*-BuOH (50 μ l) was then added. The mixture was stirred at r.t. under argon for 3 h, then dry-loaded onto SiO₂ and purified by column chromatography using a Combiflash (SiO₂, 0-20 % MeOH/CH₂Cl₂ over 15 min). The combined pure fractions were dried with MgSO₄ and evaporated under reduced pressure. **85** was obtained as a white amorphous solid (14.6 mg, 23.4 μ mol, 46.8 %).

IR (neat) ν_{max} / cm⁻¹ = 3286.7 (N-H), 2949.7 (C-H), 2820.6 (C-H), 2778.0 (C-H), 1778.1 (lactone C=O), 1725.6 (carboxylic acid C=O), 1663.7 (amide C=O), 1625.8 (quinolone C=O)

¹H NMR (500 MHz, DMSO d₆) δ / ppm = 15.22 (br s, 1 H, C(=O)OH), 8.65 (s, 1 H, *ortho* to C(=O)OH), 8.40 (d, *J* = 8.0 Hz, 1 H, NH), 7.88 (d, *J* = 13.4 Hz, 1 H, *ortho* to F), 7.85 (s, 1 H, CH=CCH₂), 7.55 (d, *J* = 7.5 Hz, 1 H, *meta* to F), 4.53 (ddd, *J* = 10.9, 9.0, 8.1 Hz, 1 H, CHNH), 4.33 (td, *J* = 8.9, 1.8 Hz, 1 H, OCHH), 4.31 (t, *J* = 7.0 Hz, 2 H, CH₂NCH=C), 4.20 (ddd, *J* = 10.5, 8.8, 6.5 Hz, 1 H, OCHH), 3.82 (tt, *J* = 6.9, 4.0 Hz, 1 H, NCH(CH₂)₂), 3.32 (br. t, *J* = 4.2 Hz, 4 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.64 (t, *J* = 7.4 Hz, 2 H, CH=CCH₂), 2.57 (br. t, *J* = 5.0 Hz, 2 H, CH₂CH₂CH₂N(CH₂)CH₂), 2.34 - 2.42 (m, 3 H, OCH₂CHH and CH=CCH₂CH₂CH₂CH₂), 2.09 - 2.19 (m, 3 H, OCH₂CHH and C(=O)CH₂), 2.02 (quin, *J* = 7.2 Hz, 2 H, C(=O)CH₂CH₂), 1.64 (quin, *J* = 7.6 Hz, 2 H, CH=CCH₂CH₂), 1.52 (quin, *J* = 7.2 Hz, 2 H, CH=CCH₂CH₂CH₂), 1.29 - 1.34 (m, 2 H, NCH(CHH)₂), 1.15 - 1.21 (m, 2 H, NCH(CHH)₂)

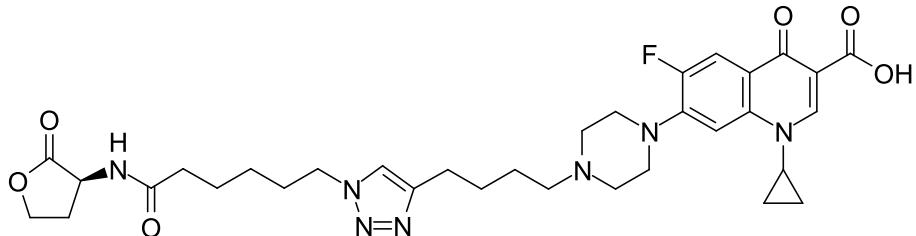
¹³C NMR (126 MHz, DMSO d₆) δ / ppm = 176.3 (C(=O)CC(=O)OH), 175.4 (OC(=O)), 171.2 (NHC(=O)), 166.0 (C(=O)OH), 153.0 (d, *J* = 248.6 Hz, *ortho* to F), 148.0 (CH=CC(=O)OH), 146.8 (CH=CCH₂), 145.2 (d, *J* = 9.6 Hz, *ipso* to piperazine), 139.2 (*para* to F), 121.7 (CH=CCH₂), 118.5 (d, *J* = 7.5 Hz, *para* to piperazine), 110.9 (d, *J* = 22.4 Hz, *ortho* to C=O and *ortho* to F), 106.7 (CC(=O)OH), 106.3 (d, *J* = 3.2 Hz, *meta* to C=O and *meta* to F), 65.3 (OCH₂), 57.3 (CH=CCH₂CH₂CH₂N), 52.4 (CH₂CH₂CH₂N(CH₂)CH₂), 49.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 49.4 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 48.6 (CH₂NCH=C), 47.9 (OC(=O)CHNH), 35.9 (NCH(CH₂)₂), 31.7 (NHC(=O)CH₂), 28.2 (CH₂CHNH), 26.9 (CH=CCH₂CH₂), 25.8 (NHC(=O)CH₂CH₂ and CH=CCH₂CH₂CH₂), 24.9 (CH=CCH₂), 7.6 (NCH(CH₂)₂)

HRMS (ESI⁺) *m/z* / Da = 624.2928, [M+H]⁺ found, [C₃₁H₃₉FN₇O₆]⁺ requires 624.2946

$[\alpha]_D^{20}$ / °10⁻¹cm²g⁻¹ = -10.6 (c / g(100 ml)⁻¹ = 0.094, MeOH)

The compound has not been reported previously.

5.28 (*S*)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(6-oxo-6-((2-oxotetrahydrofuran-3-yl)amino)hexyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 86



50 % water/*t*-BuOH (2 ml) was degassed by bubbling N₂ through it. This was then added to a mixture of 1-cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **76** (20.6 mg, 50.0 μ mol, 1 eq.) and (*S*)-6-azido-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide **69** (12.0 mg, 50.0 μ mol, 1 eq.). A similarly degassed solution of CuSO₄ · 5 H₂O (624 μ g, 2.5 μ mol, 0.05 eq. 50 mM), THPTA (1.09 mg, 2.5 μ mol, 0.05 eq. 50 mM) and sodium ascorbate (991 μ g, 5 μ mol, 0.1 eq., 100 mM) in 50 % water/*t*-BuOH (50 μ l) was then added. The mixture was stirred at r.t. under argon for 3 h, then dry-loaded onto SiO₂ and purified by column chromatography using a CombiFlash (SiO₂, 0-20 % MeOH/CH₂Cl₂ over 15 min). The combined pure fractions were dried with MgSO₄ and evaporated under reduced pressure. **86** was obtained as a white amorphous solid (12.4 mg, 19.0 μ mol, 38.0 %).

TLC R_f = 0.30 (30 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 3301.8 (N-H), 2939.7 (C-H), 2857.5 (C-H), 1784.6 (lactone C=O), 1728.5 (carboxylic acid C=O), 1658.2 (amide C=O), 1625.5 (quinolone C=O)

¹H NMR (500 MHz, DMSO d₆) δ / ppm = 15.22 (br s, 1 H, C(=O)OH), 8.65 (s, 1 H, *ortho* to C(=O)OH), 8.32 (d, *J* = 8.0 Hz, 1 H, NH), 7.89 (d, *J* = 13.3 Hz, 1 H, *ortho* to F), 7.84 (s, 1 H, CH=CCH₂), 7.55 (d, *J* = 7.6 Hz, 1 H, *meta* to F), 4.51 (ddd, *J* = 10.9, 9.1, 7.9 Hz, 1 H, CHNH), 4.33 (td, *J* = 8.8, 1.8 Hz, 1 H, OCHH), 4.28 (t, *J* = 7.1 Hz, 2 H, CH₂NCH=C), 4.19 (ddd, *J* = 10.5, 8.7, 6.6 Hz, 1 H, OCHH), 3.82 (tt, *J* = 7.0, 4.0 Hz, 1 H, NCH(CH₂)₂), 3.32 (br t, *J* = 4.5, 4 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.63 (t, *J* = 7.5 Hz, 2 H, CH=CCH₂), 2.57 (br t, *J* = 4.2 Hz, 4 H, CH₂CH₂CH₂N(CH₂)CH₂), 2.33 - 2.41 (m, 3 H, OCH₂CHH and CH=CCH₂CH₂CH₂CH₂), 2.06 - 2.16 (m, 3 H, OCH₂CHH and C(=O)CH₂), 1.79 (quin, *J* = 7.4 Hz, 2 H, C(=O)CH₂CH₂CH₂CH₂), 1.63 (quin, *J* = 7.5 Hz, 2 H, CH=CCH₂CH₂), 1.45 - 1.56 (m, 4 H, C(=O)CH₂CH₂ and CH=CCH₂CH₂CH₂), 1.29 - 1.34 (m, 2 H, NCH(CHH)₂), 1.19 - 1.25 (m, 2 H, C(=O)CH₂CH₂CH₂), 1.15 - 1.19 (m, 2 H, NCH(CHH)₂)

¹³C NMR (126 MHz, DMSO d₆) δ / ppm = 176.4 (C(=O)CC(=O)OH), 175.4 (OC(=O)), 172.1 (NHC(=O)), 166.0 (C(=O)OH), 153.0 (d, *J* = 250.2 Hz, *ipso* to F), 148.0 (CH=CC(=O)OH), 146.8 (CH=CCH₂), 145.2 (d, *J* = 9.6 Hz, *ipso* to piperazine), 139.2 (*para* to F), 121.6 (CH=CCH₂), 118.5 (d, *J* = 8.0 Hz, *para* to piperazine), 110.9 (d, *J* = 23.5 Hz, *ortho* to C=O and *ortho* to F), 106.7 (CC(=O)OH), 106.3 (d, *J* = 2.1 Hz, *meta* to C=O and *meta* to F), 65.3 (OCH₂), 57.4 (CH=CCH₂CH₂CH₂CH₂N), 52.4 (CH₂CH₂CH₂N(CH₂)CH₂), 49.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 49.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 49.0 (CH₂NCH=C), 47.8 (CHNH), 35.9 (NCH(CH₂)₂), 34.8 (NHC(=O)CH₂), 29.5 (CH₂CH₂NCH=C), 28.3 (CH₂CHNH), 26.9 (CH=C

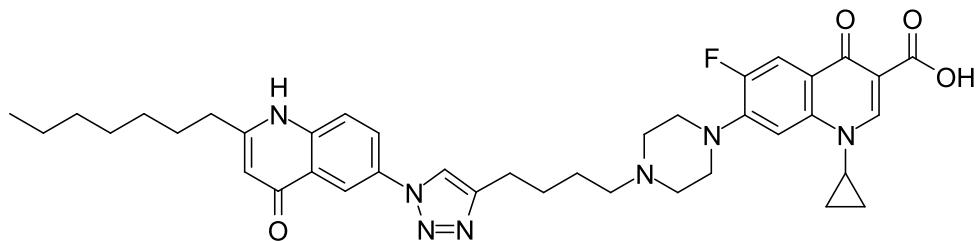
CH_2CH_2), 25.7 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2$), 25.4 ($\text{NHC}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2$), 24.9 ($\text{CH}=\text{CCH}_2$), 24.5 ($\text{NHC}(=\text{O})\text{CH}_2\text{CH}_2$), 7.6 ($\text{NCH}(\text{CH}_2)_2$)

HRMS (ESI⁺) m/z / Da = 652.3254, [M+H]⁺ found, [C₃₃H₄₃FN₇O₆]⁺ requires 652.3248

$[\alpha]_D^{20} / {}^\circ\text{10}^{-1}\text{cm}^2\text{g}^{-1} = -8.5$ ($c / \text{g}(100 \text{ ml})^{-1} = 0.106$, MeOH)

The compound has not been reported previously.

5.29 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(2-heptyl-4-oxo-1,4-dihydroquinolin-6-yl)-1H-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 88



50 % water/*t*-BuOH (1 ml) was degassed by bubbling N₂ through it. This was then added to a mixture of 1-cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **76** (4.1 mg, 10.0 μmol , 1 eq.) and 6-azido-2-heptylquinolin-4(1*H*)-one **46** (2.8 mg, 10.0 μmol , 1 eq.). A similarly degassed solution of CuSO₄ · 5H₂O (125 μg , 0.5 μmol , 0.05 eq. 50 mM), THPTA (218 μg , 0.5 μmol , 0.05 eq. 50 mM) and sodium ascorbate (198 μg , 1 μmol , 0.1 eq., 100 mM) in 50 % water/*t*-BuOH (10 μl) was then added. The mixture was stirred at r.t. under argon for 1.5 h, then the reaction mixture was evaporated under reduced pressure. The residue was purified by preparative HPLC (50-100 % acetonitrile/water over 20 min). The combined pure fractions were evaporated under reduced pressure and then partitioned between NaHCO₃ (aq., sat., 10 ml) and 10 % *i*-PrOH/CHCl₃ (10 ml). The organic layer was dried with MgSO₄ and evaporated under reduced pressure. **88** was obtained as a white amorphous solid (8.6 mg, 2.7 μmol , 27.0 %).

IR (neat) $\nu_{max} / \text{cm}^{-1} = 2927.0$ (C-H), 2865.5 (C-H), 1715.5 (carboxylic acid C=O), 1631.0 (ciprofloxacin quinolone C=O and HHQ C=O)

¹H NMR (500 MHz, DMSO d₆) 15.12 (br s, 1 H, $\text{C}(=\text{O})\text{OH}$), 11.79 (s, 1 H, NH), 8.75 (s, 1 H, NCH=CCH₂), 8.71 (s, 1 H, *ortho* to C(=O)OH), 8.40 (d, $J = 2.7$ Hz, 1 H, *ortho* to C(=O) and *ortho* to N), 8.18 (dd, $J = 8.9, 2.6$ Hz, 1 H, *para* to C(=O) and *ortho* to N), 7.99 (d, $J = 13.0$ Hz, 1 H, *ortho* to F), 7.75 (d, $J = 9.0$ Hz, 1 H, *meta* to C(=O) and *meta* to N), 7.62 (d, $J = 7.8$ Hz, 1 H, *meta* to F), 6.02 (s, 1 H, NHC=CHC(=O)), 3.85 (tt, $J = 7.0, 4.0$ Hz, 1 H, NCH(CH₂)₂), 3.23 - 3.30 (m, 10 H, CH₂N(CH₂CH₂)CH₂CH₂), 2.82 (t, $J = 5.9$ Hz, 2 H, NCH=CCH₂), 2.63 (t, $J = 7.9$ Hz, 2 H, CH₂C=CHC(=O)), 1.76 - 1.81 (m, 4 H, NCH=CCH₂CH₂CH₂), 1.70 (quin, $J = 7.2$ Hz, 2 H, CH₂CH₂C=CHC(=O)), 1.15 - 1.38 (m, 12 H, CH₃CH₂CH₂CH₂CH₂, NCH(CHH)₂ and NCH(CHH)₂), 0.87 (t, $J = 6.9$ Hz, 3 H, CH₃)

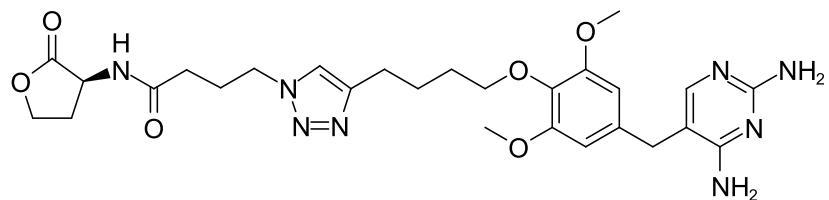
¹³C NMR (126 MHz, DMSO d₆) δ / ppm = 176.4 ($\text{C}(=\text{O})\text{CC}(=\text{O})\text{OH}$), 176.3 (CHC(=O)), 165.8 ($\text{C}(=\text{O})\text{OH}$), 154.3 (CCHC(=O)), 152.9 (d, $J = 240.1$ Hz, *ipso* to F), 148.3 ($\text{CH}=\text{CC}(=\text{O})\text{OH}$), 147.5 (NCHCCH₂), 143.0 (d, $J = 8.5$ Hz, *ortho* to F and *ipso* to N), 139.6 (*ipso* to NH), 139.0 (*para* to F), 132.0 (*para* to NH), 124.9 (*ipso*

to C(=O) and *ortho* to NH), 123.6 (*para* to C(=O) and *meta* to NH), 120.5 (NCH=CCH₂), 120.0 (*meta* to C(=O) and *meta* to N), 119.6 (d, *J* = 9.6 Hz, *ipso* to C(=O) and *para* to N), 115.1 (*ortho* to C(=O) and *ortho* to N), 111.3 (d, *J* = 28.8 Hz, *ortho* to F and *ortho* to C(=O)), 107.9 (*meta* to F and *meta* to C(=O)), 107.2 (CHC(=O)), 106.9 (CC(=O)OH), 55.4 (CH=CCH₂CH₂CH₂CH₂N), 50.6 (CH₂CH₂CH₂N(CH₂)CH₂), 46.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 46.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 36.0 (NCH(CH₂)₂), 33.2 (CH₂CNH), 31.2 (CH₃CH₂CH₂), 28.3 - 28.5 (CH₃CH₂CH₂CH₂CH₂CH₂), 25.6 (CH=CCH₂CH₂), 24.4 (CH=CCH₂), 22.7 (CH=CCH₂CH₂CH₂), 22.0 (CH₃CH₂), 13.9 (CH₃), 7.6 (NCH(CH₂)₂)

HRMS (ESI⁺) *m/z* / Da = 696.3667, [M+H]⁺ found, [C₃₉H₄₇FN₇O₄]⁺ requires 696.3668

The compound has not been reported previously.

5.30 (*S*)-4-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1*H*-1,2,3-triazol-1-yl)-*N*-(2-oxotetrahydrofuran-3-yl)butanamide 92



50 % water/*t*-BuOH (2 ml) was degassed by bubbling N₂ through it. This was then added to a mixture of 5-(4-(hex-5-yn-1-yloxy)-3,5-dimethoxybenzyl)pyrimidine-2,4-diamine **79** (20.6 mg, 50.0 μ mol, 1 eq.) and (*S*)-4-azido-*N*-(2-oxotetrahydrofuran-3-yl)butanamide **66** (15.9 mg, 75.0 μ mol, 1.5 eq.). Similarly degassed solutions of CuSO₄ · 5 H₂O (624 μ g, 2.5 μ mol, 0.05 eq. 50 mM), THPTA (1.09 mg, 2.5 μ mol, 0.05 eq. 50 mM) and sodium ascorbate (991 μ g, 5 μ mol, 0.1 eq., 100 mM) in water (50 μ l) were then added. An extra portion of **66** (10.6 mg, 50.0 μ mol, 1 eq.) was added after 4 d. Extra portions of the catalysts were added after 9 d. After 2 weeks, the reaction mixture was extracted with CH₂Cl₂ (6×10 ml) then dry-loaded onto SiO₂ and purified by column chromatography using a CombiFlash (SiO₂, 0-20 % MeOH/CH₂Cl₂). The combined pure fractions were dried with MgSO₄ and evaporated under reduced pressure. **92** was obtained as a pale brown gum (4.8 mg, 8.4 μ mol, 16.8 %).

TLC *R_f* = 0.30 (30 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 3340.5 (N-H), 3303.3 (N-H), 3182.5 (N-H), 2933.8 (C-H), 1774.2 (lactone C=O), 1659.7 (amide C=O and pyrimidine)

¹H NMR (500 MHz, DMSO d₆) δ / ppm = 8.43 (d, *J* = 8.0 Hz, 1 H, NH), 7.80 (s, 1 H, NCH=CCH₂), 7.46 (s, 1 H, CHN=CNH₂), 6.68 (br s, 2 H, CH₂CCNH₂), 6.53 (s, 2 H, *meta* to CH₂), 6.21 (br s, 2 H, CHN=CNH₂), 4.49 (dt, *J* = 10.7, 8.6 Hz, 1 H, CHNH), 4.32 (td, *J* = 8.7, 1.6 Hz, 1 H, CHHOC(=O)), 4.29 (t, *J* = 6.8 Hz, 2 H, CH₂N), 4.19 (ddd, *J* = 10.6, 8.7, 6.5 Hz, 1 H, CHHOC(=O)), 3.79 (t, *J* = 6.2 Hz, 2 H, CH₂CH₂CH₂O), 3.68 (s, 6 H, CH₃), 3.53 (br s, 2 H, CCH₂C), 2.63 (t, *J* = 7.5 Hz, 2 H, CH=CCH₂), 2.37 (dddd, *J* = 12.2, 8.9, 6.7, 1.8 Hz, 1 H, CHHCHNH), 2.08 - 2.15 (m, 3 H, CHHCHNH and C(=O)CH₂), 2.00 (quin, *J* = 7.2 Hz, 2 H, CH₂CH₂N), 1.72 (quin, *J* = 7.3 Hz, 2 H, CH=CCH₂CH₂), 1.61 (quin, *J* = 6.7 Hz, 2 H, CH₂CH₂O)

¹³C NMR (126 MHz, DMSO d₆) δ / ppm = 175.8 (OC=O), 171.9 (NHC=O), 163.1 (CC(NH₂)N), 159.7

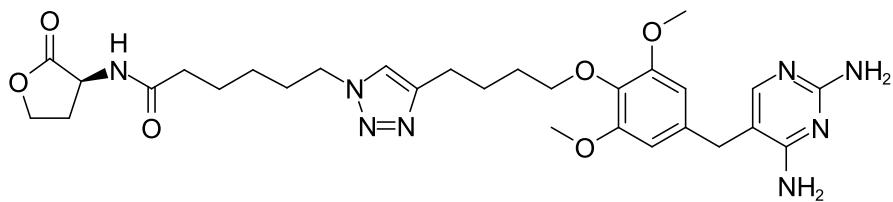
(br s, $\underline{\text{NC}}(\text{NH}_2)\text{N}$), 153.2 (*ipso* to OCH_3), 150.5 (br s, $\underline{\text{CH}}\text{NC}(\text{NH}_2)\text{N}$), 147.3 ($\text{NCH}=\underline{\text{CCH}_2\text{CH}_2}$), 135.2 (*para* to CH_2O), 135.0 (*ipso* to CH_2O), 122.1 ($\underline{\text{CH}}=\text{CCH}_2\text{CH}_2$), 107.3 ($\text{CH}_2\underline{\text{C}}(\text{NH}_2)=\text{N}$), 106.2 (*meta* to CH_2O), 72.3 ($\text{CH}_2\text{CH}_2\underline{\text{CH}_2\text{O}}$), 65.7 ($\underline{\text{OCH}_2\text{CH}_2\text{CHNH}}$), 56.2 ($\underline{\text{OCH}_3}$), 48.9 ($\underline{\text{CH}_2\text{N}}$), 48.3 ($\underline{\text{CHNH}}$), 32.9 ($\underline{\text{CCH}_2\text{C}}$), 32.0 ($\text{C}=(\text{O})\underline{\text{CH}_2}$), 29.3 ($\text{CH}_2\underline{\text{CH}_2\text{CH}_2\text{O}}$), 28.4 ($\text{OCH}_2\underline{\text{CH}_2\text{CHNH}}$), 26.0 ($\underline{\text{CH}_2\text{CH}_2\text{N}}$), 25.7 ($\text{CH}=\underline{\text{CCH}_2\text{CH}_2}$), 24.9 ($\text{CH}=\underline{\text{CCH}_2\text{CH}_2}$)

HRMS (ESI⁺) m/z / Da = 569.2834, [M+H]⁺ found, [C₂₇H₃₇N₈O₆]⁺ requires 569.2836

$[\alpha]_D^{20} / {}^\circ\text{10}^{-1}\text{cm}^2\text{g}^{-1} = -4.6$ ($c / \text{g}(100 \text{ ml})^{-1} = 0.0433$, MeOH)

The compound has not been reported previously.

5.31 (*S*)-6-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1*H*-1,2,3-triazol-1-yl)-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide 93



50 % water/*t*-BuOH (2 ml) was degassed by bubbling N_2 through it. This was then added to a mixture of 5-(4-(hex-5-yn-1-yloxy)-3,5-dimethoxybenzyl)pyrimidine-2,4-diamine **79** (20.6 mg, 50.0 μmol , 1 eq.) and (*S*)-6-azido-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide **69** (18.0 mg, 75.0 μmol , 1.5 eq.). Similarly degassed solutions of $\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}$ (624 μg , 2.5 μmol , 0.05 eq. 50 mM), THPTA (1.09 mg, 2.5 μmol , 0.05 eq. 50 mM) and sodium ascorbate (991 μg , 5 μmol , 0.1 eq., 100 mM) in water (50 μl) were then added. An extra portion of **69** (12.0 mg, 50.0 μmol , 1 eq.) was added after 4 d. Extra portions of the catalysts were added after 9 d. After 2 weeks the reaction mixture was extracted with CH_2Cl_2 ($6 \times 10 \text{ ml}$) then dry-loaded onto SiO_2 and purified by column chromatography using a Combiflash (SiO_2 , 0-20 % MeOH/ CH_2Cl_2). The combined pure fractions were dried with MgSO_4 and evaporated under reduced pressure. **93** was obtained as a clear gum (8.0 mg, 13.4 μmol , 26.8 %).

TLC $R_f = 0.35$ (30 % MeOH/ CH_2Cl_2)

IR (neat) $\nu_{max} / \text{cm}^{-1} = 3336.0$ (N-H), 3208.7 (N-H), 2941.1 (C-H), 2869.2 (C-H), 1775.2 (lactone C=O), 1657.3 (amide C=O and pyrimidine)

¹H NMR (500 MHz, DMSO d₆) $\delta / \text{ppm} = 8.34$ (d, $J = 8.0 \text{ Hz}$, 1 H, $\underline{\text{NH}}$), 7.83 (s, 1 H, $\text{NCH}=\underline{\text{CCH}_2}$), 7.50 (s, 1 H, $\underline{\text{CHN}}=\text{CNH}_2$), 6.54 (s, 2 H, *meta* to CH_2), 6.17 (br s, 2 H, $\text{CH}_2\underline{\text{CCN}}\text{H}_2$), 5.77 (br s, 2 H, $\text{CHN}=\underline{\text{CNH}}_2$), 4.51 (ddd, $J = 11.0, 9.0, 8.1 \text{ Hz}$, 1 H, $\underline{\text{CHNH}}$), 4.33 (td, $J = 8.8, 1.9 \text{ Hz}$, 1 H, $\underline{\text{CHHOC}}(=\text{O})$), 4.27 (t, $J = 7.1 \text{ Hz}$, 2 H, $\underline{\text{CH}_2\text{N}}$), 4.19 (ddd, $J = 10.5, 8.7, 6.5 \text{ Hz}$, 1 H, $\underline{\text{CHHOC}}(=\text{O})$), 3.80 (t, $J = 6.3 \text{ Hz}$, 2 H, $\text{CH}_2\text{CH}_2\text{CH}_2\text{O}$), 3.70 (s, 6 H, $\underline{\text{CH}_3}$), 3.52 (s, 2 H, $\underline{\text{CCH}_2\text{C}}$), 2.64 (t, $J = 7.5 \text{ Hz}$, 2 H, $\text{CH}=\underline{\text{CCH}_2}$), 2.36 (dddd, $J = 12.1, 8.9, 6.7, 1.8 \text{ Hz}$, 1 H, $\underline{\text{CHHCHNH}}$), 2.06 - 2.16 (m, 3 H, $\underline{\text{CHHCHNH}}$ and $\text{C}=(\text{O})\underline{\text{CH}_2}$), 1.78 (quin, $J = 7.4 \text{ Hz}$, 2 H, $\underline{\text{CH}_2\text{CH}_2\text{N}}$), 1.73 (quin, $J = 7.7 \text{ Hz}$, 2 H, $\text{CH}=\underline{\text{CCH}_2\text{CH}_2}$), 1.63 (quin, $J = 6.8 \text{ Hz}$, 2 H, $\underline{\text{CH}_2\text{CH}_2\text{O}}$), 1.52 (quin, $J = 7.5 \text{ Hz}$, 2 H, $\text{C}=(\text{O})\underline{\text{CH}_2\text{CH}_2}$), 1.17 - 1.27 (m, 2 H, $\text{C}=(\text{O})\underline{\text{CH}_2\text{CH}_2\text{CH}_2}$)

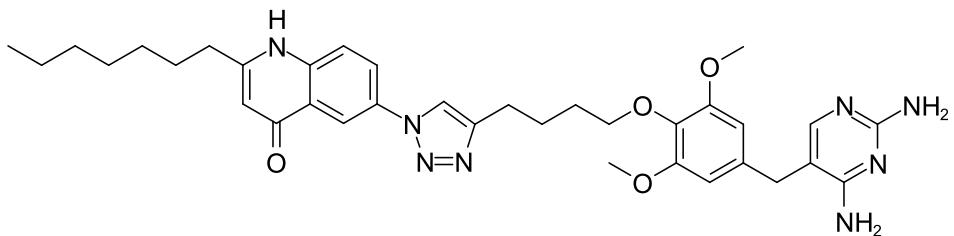
¹³C NMR (125 MHz, DMSO d₆) δ / ppm = 175.4 (OC=O), 172.0 (NHC=O), 162.2 (CC(NH₂)N), 161.8 (NC(NH₂)N), 154.8 (CHNC(NH₂)N), 152.8 (*ipso* to OCH₃), 146.7 (CH=CCH₂CH₂), 135.5 (*para* to CH₂O), 134.8 (*ipso* to CH₂O), 121.6 (CH=CCH₂CH₂), 105.9 (CH₂CC(NH₂)=N), 105.8 (*meta* to CH₂O), 71.9 (CH₂CH₂CH₂O), 65.2 (OCH₂CH₂CHNH), 55.8 (OCH₃), 49.0 (CH₂N), 47.8 (CHNH), 34.8 (C(=O)CH₂), 32.9 (CCH₂C), 29.4 (CH₂CH₂N), 29.1 (CH₂CH₂CH₂O), 28.2 (OCH₂CH₂CHNH), 25.5 (CH=CCH₂CH₂), 25.3 (C(=O)CH₂CH₂CH₂), 24.7 (CH=CCH₂CH₂), 24.4 (C(=O)CH₂CH₂)

HRMS (ESI⁺) *m/z* / Da = 597.3149, [M+H]⁺ found, [C₂₉H₄₁N₈O₆]⁺ requires 597.3144

$[\alpha]_D^{20} / {}^\circ 10^{-1} \text{cm}^2 \text{g}^{-1} = -3.6$ (*c* / g(100 ml)⁻¹ = 0.11, MeOH)

The compound has not been reported previously.

5.32 6-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1*H*-1,2,3-triazol-1-yl)-2-heptylquinolin-4(*1H*)-one 95



50 % water/t-BuOH (1 ml) was degassed by bubbling N₂ through it. This was then added to a mixture of 5-(4-(hex-5-yn-1-yloxy)-3,5-dimethoxybenzyl)pyrimidine-2,4-diamine **79** (3.6 mg, 10.0 μ mol, 1 eq.) and 6-azido-2-heptylquinolin-4(*1H*)-one **46** (2.8 mg, 10.0 μ mol, 1 eq.). A similarly degassed solution of CuSO₄ · 5 H₂O (125 μ g, 0.5 μ mol, 0.05 eq. 50 mM), THPTA (218 μ g, 0.5 μ mol, 0.05 eq. 50 mM) and sodium ascorbate (198 μ g, 1 μ mol, 0.1 eq., 100 mM) in water (10 μ l) was then added. The mixture was stirred at r.t. under argon for 1.5 h, then evaporated under reduced pressure. The residue was purified by preparative HPLC (5-100 % acetonitrile/water over 20 min). The combined pure fractions were evaporated under reduced pressure and then partitioned between NaHCO₃ (aq., sat., 10 ml) and 10 % *i*-PrOH/CHCl₃ (10 ml). The organic layer was dried with MgSO₄ and evaporated under reduced pressure. **95** was obtained as a clear gum (2.6 mg, 4.1 μ mol, 41.0 %).

TLC R_f = 0.17 (20 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 2927.7 (C-H), 2855.5 (C-H), 1664.1 (pyrimidine), 1645.4 (pyrimidine and HHQ C=O)

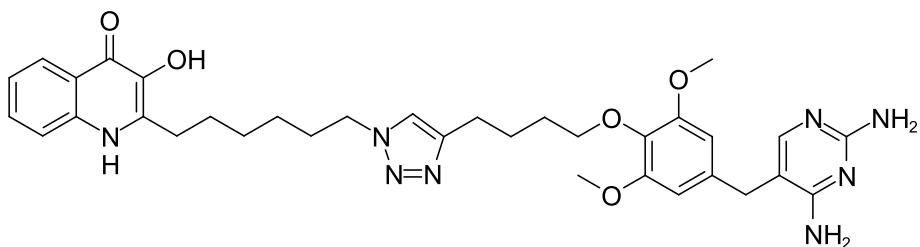
¹H NMR (500 MHz, DMSO d₆) δ / ppm = 11.80 (s, 1 H, NH), 8.69 (s, 1 H, NCH=CCH₂), 8.41 (d, *J* = 2.7 Hz, 1 H, *ortho* to C=O), 8.17 (dd, *J* = 9.0, 2.6 Hz, 1 H, *para* to C=O), 7.73 (d, *J* = 9.0 Hz, 1 H, *ortho* to NH), 7.51 (br s, 4 H, NH₂), 7.41 (s, 1 H, CHN=CNH₂), 6.61 (s, 2 H, *meta* to CH₂), 6.02 (d, *J* = 1.8 Hz, 1 H, C(=O)CH), 3.86 (t, *J* = 6.3 Hz, 2 H, CH₂O), 3.73 (s, 6 H, OCH₃), 3.57 - 3.62 (m, 2 H, CCH₂C), 2.78 (t, *J* = 7.5 Hz, 2 H, CH=CCH₂), 2.63 (t, *J* = 7.3 Hz, 2 H, HNCCH₂), 1.85 (quin, *J* = 7.5 Hz, 2 H, CH=CCH₂CH₂), 1.61 - 1.78 (m, 4 H, HNCCH₂CH₂ and CH=CCH₂CH₂CH₂), 1.31 - 1.40 (m, 4 H, HNCCH₂CH₂CH₂CH₂), 1.25 - 1.31 (m, 4 H, CH₃CH₂CH₂), 0.86 (t, *J* = 7.2 Hz, 3 H, CH₃CH₂)

¹³C NMR (125 MHz, DMSO d₆) δ / ppm = 176.4 (C=O), 164.1 (CC(NH₂)N), 154.3 (HNC), 154.2 (NC(NH₂)N), 153.1 (*ipso* to OCH₃), 148.3 (CH=CCH₂CH₂), 140.2 (CHNC(NH₂)N), 139.6 (*ipso* to NH), 135.4 (*ipso* to CH₂O), 132.8 (*para* to CH₂O), 132.1 (*para* to NH), 124.9 (*ipso* to C=O), 123.7 (*para* to C=O), 120.3 (CH=CCH₂CH₂), 120.0 (*meta* to C=O and *ortho* to NH), 115.1 (*ortho* to C=O and *meta* to NH), 109.0 (CH₂CC(NH₂)=N), 108.0 (C(=O)CH), 106.3 (*meta* to CH₂O), 72.0 (CH₂CH₂CH₂O), 56.0 (OCH₃), 33.3 (HNCCH₂), 32.1 (CCH₂C), 31.2 (CH₃CH₂CH₂), 29.1 (CH₂CH₂O), 28.3 - 28.6 (CH₃CH₂CH₂CH₂CH₂CH₂), 25.3 (CH₂CH₂CH₂O), 24.7 (CH=CCH₂), 22.1 (CH₃CH₂), 14.0 (CH₃CH₂)

HRMS (ESI⁺) *m/z* / Da = 641.3557, [M+H]⁺ found, [C₃₅H₄₅N₈O₄]⁺ 641.3558

The compound has not been reported previously.

5.33 2-(6-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1*H*-1,2,3-triazol-1-yl)hexyl)-3-hydroxyquinolin-4(1*H*)-one 97



50 % water/*t*-BuOH (1 ml) was degassed by bubbling N₂ through it. This was then added to a mixture of 5-(4-(hex-5-yn-1-yloxy)-3,5-dimethoxybenzyl)pyrimidine-2,4-diamine **79** (14.2 mg, 39.8 μ mol, 1 eq.) and 2-(6-azidohexyl)-3-hydroxyquinolin-4(1*H*)-one **28** (11.4 mg, 39.8 μ mol, 1 eq.). A similarly degassed solution of CuSO₄ · 5 H₂O (1.25 mg, 5 μ mol, 0.125 eq. 50 mM), THPTA (2.18 mg, 5 μ mol, 0.125 eq. 50 mM) and sodium ascorbate (1.98 mg, 10 μ mol, 0.25 eq., 100 mM) in water (100 μ l) was then added. The mixture was stirred at r.t. under argon for 3 h, then MeOH (1 ml) was added and the reaction mixture was dry-loaded onto SiO₂ and purified by column chromatography (SiO₂, 0-20 % MeOH/CH₂Cl₂). The combined pure fractions were dried with MgSO₄ and evaporated under reduced pressure. **97** was obtained as a pale brown amorphous solid (4.7 mg, 7.3 μ mol, 18.3 %).

TLC R_f = 0.21 (20 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 2924.8 (C-H), 2853.4 (C-H), 1660.0 (pyrimidine), 1638.8 (pyrimidine and PQS C=O)

¹H NMR (500 MHz, DMSO d₆) δ / ppm = 11.53 (br s, 1 H, NH), 8.09 (d, *J* = 8.0 Hz, 1 H, *ortho* to C=O), 7.83 (s, 1 H, NCH=CCH₂), 7.48 - 7.57 (m, 3 H, *para* to C=O, *ortho* to NH and CHN=CNH₂), 7.21 (ddd, *J* = 8.0, 6.3, 1.5 Hz, 1 H, *para* to NH), 6.55 (s, 2 H, *meta* to CH₂), 4.28 (t, *J* = 7.1 Hz, 2 H, CH₂N), 3.80 (t, *J* = 6.2 Hz, 2 H, CH₂O), 3.70 (s, 6 H, CH₃), 3.53 (d, *J* = 0.3 Hz, 2 H, CCH₂C), 2.73 (t, *J* = 7.5 Hz, 2 H, HNCCH₂), 2.64 (t, *J* = 7.4 Hz, 2 H, CH=CCH₂), 1.80 (quin, *J* = 7.4 Hz, 2 H, CH₂CH₂N), 1.73 (quin, *J* = 7.5 Hz, 2 H, CH=CCH₂CH₂), 1.66 (quin, *J* = 7.2 Hz, 2 H, HNCCH₂CH₂), 1.62 (quin, *J* = 6.8 Hz, 2 H, CH₂CH₂O), 1.33 - 1.40 (m, 2 H, HNCCH₂CH₂CH₂), 1.27 - 1.32 (m, 2 H, HNCCH₂CH₂CH₂CH₂)

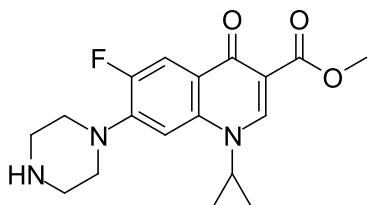
¹³C NMR (125 MHz, DMSO d₆) δ / ppm = 168.9 (C=O), 162.5 (CC(NH₂)N), 162.5 (NC(NH₂)N), 152.9 (CHNC(NH₂)N), 152.8 (*ipso* to OCH₃), 146.8 (CH=CCH₂CH₂), 137.7 (COH), 137.3 (*para* to OH), 135.4

(HNC), 135.1 (*para* to CH₂O), 134.8 (*ipso* to CH₂O), 129.9 (*para* to C=O), 124.4 (*ortho* to C=O and *meta* to NH), 122.1 (*ipso* to C=O), 121.5 (*para* to NH), 121.4 (CH=CCH₂CH₂), 117.7 (*meta* to C=O and *ortho* to NH), 106.2 (CH₂CC(NH₂)=N), 105.8 (*meta* to CH₂O), 71.9 (CH₂CH₂CH₂O), 55.8 (OCH₃), 49.0 (CH₂N), 32.8 (CCH₂C), 29.5 (CH₂CH₂N), 29.0 (CH₂CH₂O), 28.1 (HNCCH₂CH₂CH₂), 27.9 (HNCCH₂), 27.6 (HNCCH₂CH₂), 25.6 (CH₂CH₂CH₂N), 25.4 (CH₂CH₂CH₂O), 24.6 (CH=CCH₂CH₂)

HRMS (ESI⁺) *m/z* / Da = 643.3365, [M+H]⁺ found, [C₃₄H₄₃N₈O₅]⁺ requires 643.3351

The compound has not been reported previously.

5.34 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 108



Ciprofloxacin **24** (10.0 g, 30 mmol, 1 eq.) and *p*-toluenesulfonic acid (8.60 mg, 44.5 mmol, 1.5 eq.) were refluxed in methanol (500 ml) for 72 h. The mixture was cooled to room temperature and NaHCO₃ (sat., aq., 100 ml) and water (300 ml) were added. The product was extracted with CH₂Cl₂ (2×400 ml). The combined organic fractions were dried over MgSO₄ and evaporated under reduced pressure. **108** was obtained as a white amorphous solid (9.16 g, 26.5 mmol, 83.3 %).

TLC *R_f* = 0.13 (5 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 2947.9 (C-H), 2834.9 (C-H), 1720.9 (ester C=O), 1616.8 (quinolone C=O)

¹H NMR (400 MHz, MeOD) δ / ppm = 8.55 (s, 1 H, *ortho* to C(=O)OCH₃), 7.71 (d, *J* = 13.5 Hz, 1 H, *ortho* to F), 7.41 (d, *J* = 7.2 Hz, 1 H, *meta* to F), 3.83 (s, 3 H, CH₃), 3.62 (tt, *J* = 7.4, 3.5 Hz, 1 H, NCH(CH₂)₂), 3.24 - 3.29 (m, 4 H, HN(CH₂CH₂)CH₂CH₂), 3.02 - 3.10 (m, 4 H, HN(CH₂)CH₂), 1.31 - 1.38 (m, 2 H, NCH(CHH)₂), 1.12 - 1.20 (m, 2 H, NCH(CHH)₂)

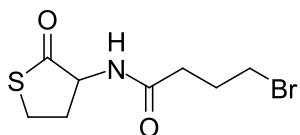
¹³C NMR (101 MHz, MeOD) δ / ppm = 175.2 (C(=O)CC(=O)OCH₃), 166.8 (C(=O)OCH₃), 154.9 (d, *J* = 248.0 Hz, *ipso* to F), 150.1 (C=CC(=O)OCH₃), 146.6 (d, *J* = 10.4 Hz, *ipso* to piperazine), 139.9 (*para* to F), 123.3 (d, *J* = 6.9 Hz, *para* to piperazine), 113.0 (d, *J* = 23.4 Hz, *ortho* to C=O and *ortho* to F), 110.1 (C(=O)OCH₃), 107.1 (d, *J* = 3.5 Hz, *meta* to C=O and *meta* to F), 52.3 (CH₃), 51.7 (HN(CH₂CH₂)CH₂CH₂), 51.6 (HN(CH₂CH₂)CH₂CH₂), 46.5 (HN(CH₂)CH₂), 36.4 (NCH(CH₂)₂), 8.7 (NCH(CH₂)₂)

¹⁹F NMR (376.45 MHz, MeOD) δ / ppm = -124.8 (s, ciprofloxacin F)

HRMS (ESI⁺) *m/z* / Da = 346.1569, [M+H]⁺ found, [C₁₈H₂₁FN₃O₃]⁺ requires 346.1567

The data are consistent with the literature.¹⁶⁶

5.35 4-Bromo-*N*-(2-oxotetrahydrothiophen-3-yl)butanamide 110



3-Aminodihydrothiophen-2(3*H*)-one hydrochloride **109** (15.0 g, 97.6 mmol, 1 eq.) and NaHCO₃ (16.4 g, 195 mmol, 2 eq.) were added to CH₂Cl₂ (150 ml) and water (150 ml). 4-Bromobutyryl chloride **64** (11.3 ml, 107 mmol, 1.1 eq.) was added dropwise over 45 min at 0 °C and the mixture was stirred for a further 1 h. The organic layer was separated and the aqueous layer was extracted with a second portion of CH₂Cl₂ (150 ml). The combined organic layers were dried over MgSO₄ and evaporated under reduced pressure. **110** was obtained as a white, amorphous solid (22.7 g, 85.8 mmol, 87.9 %).

TLC R_f = 0.19 (50 % EtOAc/PE)

IR (neat) ν_{max} / cm⁻¹ = 3265.9 (amide N-H), 3063.2 (amide N-H), 1694.3 (thiolactone C=O), 1650.5 (amide C=O)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 6.08 (d, J = 6.1 Hz, 1 H, NH), 4.54 (dt, J = 12.9, 6.5 Hz, 1 H, CHNH), 3.49 (t, J = 6.4 Hz, 2 H, CH₂Br), 3.37 (ddd, J = 12.2, 11.5, 5.3 Hz, 1 H, SCHH), 3.26 (ddd, J = 11.5, 6.9, 1.3 Hz, 1 H, SCHH), 2.91 (dddd, J = 12.5, 6.7, 5.3, 1.3 Hz, 1 H, SCH₂CHH), 2.45 (t, J = 7.4 Hz, 1 H, C(=O)CHH), 2.45 (t, J = 6.8 Hz, 1 H, C(=O)CHH), 2.20 (quin, J = 6.7 Hz, 1 H, C(=O)CH₂CH₂), 1.96 (dddd, J = 12.7, 12.5, 12.2, 7.0 Hz, 1 H, SCH₂CHH)

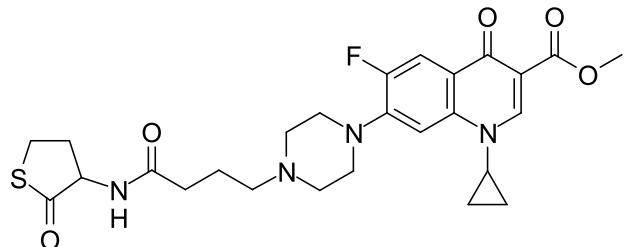
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 205.4 (SC(=O)), 172.1 (NHC(=O)), 59.4 (CHNH), 34.1 (C(=O)CH₂), 33.1 (CH₂Br), 31.8 (SCH₂CH₂), 28.0 (C(=O)CH₂CH₂), 27.5 (SCH₂)

HRMS (ESI⁺) The compound does not ionise.

The compound has been synthesised previously^{134,135} but characterisation was not published.

works
in
LCMS
see
Lois283

5.36 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 111



Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate **108** (50 mg, 0.145 mmol, 1 eq.), 4-bromo-*N*-(2-oxotetrahydrothiophen-3-yl)butanamide **110** (34.5 mg, 0.145 mmol, 1 eq.) and K₂CO₃ (20 mg, 0.145 mmol, 1 eq.) were stirred in acetonitrile (2 ml) at 50 °C under argon. After 24 h a further portion of **110** (34.5 mg, 0.145 mmol, 1 eq.) was added. After another 24 h a further portion was added (69.0

mg, 0.290 mmol, 2 eq.). After another 24 h the temperature was raised so the mixture was at reflux. After a final 24 h the precipitate was filtered off and the filtrate was purified by column chromatography (SiO₂, 5-10 % MeOH/CH₂Cl₂) followed by preparative HPLC (5-95 % acetonitrile/water over 20 min). **111** was obtained as a pale cream amorphous solid (9.4 mg, 0.018 mmol, 12.2 %).

TLC R_f = 0.47 (10 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 2944.2 (C-H), 2832.4 (C-H), 1722.4 (ester C=O), 1700.4 (thiolactone C=O), 1669.6 (amide C=O), 1617.3 (quinolone C=O)

¹H NMR (500 MHz, MeOD) δ / ppm = 8.53 (s, 1 H, *ortho* to C(=O)OCH₃), 7.68 (d, J = 13.4 Hz, 1 H, *ortho* to F), 7.41 (d, J = 7.3 Hz, 1 H, *meta* to F), 4.67 (dd, J = 12.9, 6.9 Hz, 1 H, CH₂NH), 3.83 (s, 3 H, OCH₃), 3.61 (tt, J = 6.9, 4.1 Hz, 1 H, NCH(CH₂)₂), 3.39 - 3.49 (m, 1 H, SCH₂H), 3.26 - 3.33 (m, 5 H, SCH₂H and CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.93 - 3.03 (m, 4 H, CH₂CH₂CH₂N(CH₂)CH₂), 2.79 (br. t, J = 7.2, 7.2 Hz, 2 H, C(=O)CH₂CH₂CH₂), 2.59 (dd, J = 12.4, 6.9, 5.4, 1.4 Hz, 1 H, SCH₂CH₂H), 2.39 (t, J = 7.20 Hz, 1 H, C(=O)CH₂H), 2.38 (t, J = 6.94 Hz, 1 H, C(=O)CH₂H), 2.18 (qd, J = 12.4, 7.0 Hz, 1 H, SCH₂CH₂H), 1.97 (quin, J = 7.2 Hz, 2 H, C(=O)CH₂CH₂), 1.32 - 1.37 (m, 2 H, NCH(CH₂H)₂), 1.13 - 1.19 (m, 2 H, NCH(CH₂H)₂)

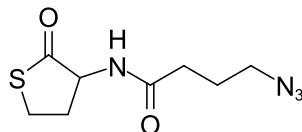
¹³C NMR (126 MHz, MeOD) δ / ppm = 207.0 (SC(=O)), 175.7 (NHC(=O)), 175.1 (C(=O)CC(=O)OCH₃), 166.6 (C(=O)OCH₃), 154.7 (d, J = 249.0 Hz, *ipso* to F), 150.2 (s, CH=CC(=O)OCH₃), 145.6 (d, J = 10.6 Hz, *ipso* to piperazine), 139.8 (*para* to F), 123.5 (d, J = 6.9 Hz, *para* to piperazine), 113.1 (d, J = 23.6 Hz, *ortho* to C=O and *ortho* to F), 110.0 (CC(=O)OCH₃), 107.4 (*meta* to C=O and *meta* to F), 60.2 (CH₂NH), 58.5 (C(=O)CH₂CH₂CH₂), 53.8 (CH₂CH₂CH₂N(CH₂)CH₂), 52.3 (OCH₃), 50.1 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 50.0 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 36.5 (NCH(CH₂)₂), 34.5 (C(=O)CH₂), 31.7 (SCH₂CH₂), 28.1 (SCH₂), 22.9 (C(=O)CH₂CH₂CH₂), 8.7 (NCH(CH₂)₂)

¹⁹F NMR (376.45 MHz, MeOD) δ / ppm = -125.4 (s, ciprofloxacin F)

HRMS (ESI⁺) m/z / Da = 531.2083, [M+H]⁺ found, [C₂₆H₃₂FN₄O₅S]⁺ requires 531.2077

The compound has been synthesised previously.^{134,135} Only HRMS characterisation was published, and this agrees with the result above.

5.37 4-Azido-N-(2-oxotetrahydrothiophen-3-yl)butanamide **112**



4-Bromo-N-(2-oxotetrahydrothiophen-3-yl)butanamide **110** (6.00 g, 27.0 mmol, 1 eq.) and NaN₃ (3.51 g, 54.1 mmol, 2 eq.) were refluxed in acetonitrile (120 ml) for 1.5 h. The solvent was evaporated under reduced pressure and the residue was partitioned between water (150 ml) and CH₂Cl₂ (150 ml). The aqueous layer was extracted twice more with CH₂Cl₂ (2×150 ml) and the combined organic fractions were dried with MgSO₄ and evaporated under reduced pressure. **112** was obtained as a yellow, sticky solid (4.60 g, 20.1 mmol, 89.3 %).

TLC R_f = 0.19 (50 % EtOAc/PE)

IR (neat) ν_{max} / cm⁻¹ = 3285.6 (N-H), 2963.9 (C-H), 2100.2 (azide), 1697.4 (thiolactone C=O), 1647.4 (amide C=O)

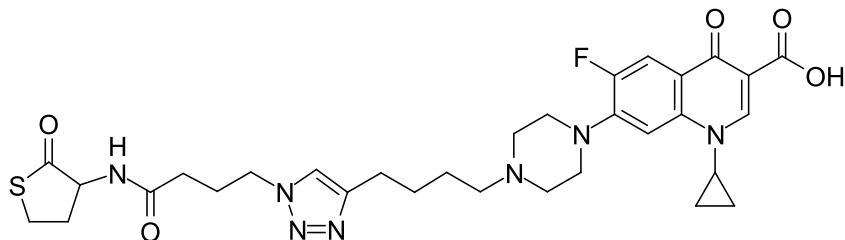
¹H NMR (400 MHz, CDCl₃) δ / ppm = 6.71 (d, J = 7.3 Hz, 1 H, NH), 4.54 (dt, J = 13.0, 7.0 Hz, 1 H, CHNH), 3.30 (t, J = 6.7 Hz, 2 H, CH₂N₃), 3.31 (td, J = 11.7, 5.3 Hz, 1 H, SCHH), 3.19 (ddd, J = 11.3, 7.0, 1.2 Hz, 1 H, SCHH), 2.70 (dddd, J = 12.4, 6.8, 5.3, 1.2 Hz, 1 H, SCH₂CHH), 2.29 (t, J = 7.5 Hz, 1 H, C(=O)CHH), 2.28 (t, J = 7.1 Hz, 1 H, C(=O)CHH), 1.97 (qd, J = 12.4, 7.0 Hz, 1 H, SCH₂CHH), 1.85 (quin, J = 6.9 Hz, 2 H, C(=O)CH₂CH₂)

¹³C NMR (101 MHz, CDCl₃) δ / ppm = 205.4 (SC(=O)), 172.3 (NHC(=O)), 59.4 (CHNH), 50.6 (CH₂N₃), 32.8 (C(=O)CH₂), 31.8 (SCH₂CH₂), 27.5 (SCH₂), 24.6 (C(=O)CH₂CH₂)

HRMS (ESI⁺) m/z / Da = 251.0565, [M+Na]⁺ found, [C₈H₁₂N₄NaO₂S]⁺ requires 251.0573

The compound has not been reported previously.

5.38 1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 113



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **76** (15 mg, 36.7 μ mol, 1 eq.) and 4-azido-*N*-(2-oxotetrahydrothiophen-3-yl)butanamide **112** (12.5 mg, 55.1 μ mol, 1.5 eq.) were dissolved in 1:9:10 water/*t*-BuOH/DMSO (3 ml), and the mixture was degassed by bubbling N₂ through it. A solution of CuSO₄ and THPTA (182 μ l, 18.2 μ mol, 0.5 eq. 100 mM, aq.) was added, followed by a solution of sodium ascorbate (367 μ l, 36.7 μ mol, 1 eq., 100 mM, aq.). The mixture was stirred at r.t. under argon for 4 d. Water (10 ml) and 10 % *i*-PrOH/CHCl₃ (10 ml) were added, the organic layer was separated and the aqueous layer was extracted again with 10 % *i*-PrOH/CHCl₃ (2×10 ml). The combined organic layers were dried with MgSO₄ and evaporated under reduced pressure. The residue was purified by preparative HPLC (5-95 % acetonitrile/water over 20 min). The combined pure fractions were evaporated under reduced pressure and then partitioned between NaHCO₃ (aq., sat., 50 ml) and 10 % *i*-PrOH/CHCl₃ (50 ml). The organic layer was dried with MgSO₄ and evaporated under reduced pressure. **113** was obtained as a white amorphous solid (16.5 mg, 25.9 μ mol, 70.6 %).

IR (neat) ν_{max} / cm⁻¹ = 2918.8 (C-H), 1712.7 (carboxylic acid C=O and thiolactone C=O), 1657.6 (amide C=O), 1626.8 (quinolone C=O), 1616.2 (triazole)

¹H NMR (500 MHz, DMSO d₆) δ / ppm = 15.23 (br s, 1 H, C(=O)OH), 8.66 (s, 1 H, *ortho* to C(=O)OH), 8.23 (d, J = 8.5 Hz, 1 H, NH), 7.90 (d, J = 13.4 Hz, 1 H, *ortho* to F), 7.84 (s, 1 H, CH=CC₂), 7.56 (d, J = 7.5 Hz, 1 H, *meta* to F), 4.59 (ddd, J = 12.7, 8.4, 6.8 Hz, 1 H, CHNH), 4.31 (t, J = 7.0 Hz, 2 H,

$\text{CH}_2\text{NCH}=\text{C}$), 3.80 - 3.86 (6.9, 4.0 Hz, 1 H, $\text{NCH}(\text{CH}_2)_2$), 3.34 - 3.37 (m, 1 H, SCHH), 3.32 (br t, $J = 4.1$ Hz, 4 H, $\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)\text{CH}_2\text{CH}_2$), 3.27 (ddd, $J = 11.1, 6.9, 1.4$ Hz, 1 H, SCHH), 2.64 (t, $J = 7.6$ Hz, 2 H, $\text{CH}=\text{CCH}_2$), 2.57 (br t, $J = 4.7$ Hz, 4 H, $\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2)\text{CH}_2$), 2.34 - 2.44 (m, 3 H, SCH_2CHH and $\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2$), 2.12 (t, $J = 7.9$ Hz, 1 H, $\text{C}(\text{=O})\text{CHH}$), 2.12 (t, $J = 7.0$ Hz, 1 H, $\text{C}(\text{=O})\text{CHH}$), 2.04 (m, 3 H, SCH_2CHH and $\text{C}(\text{=O})\text{CH}_2\text{CH}_2$), 1.64 (quin, $J = 7.5$ Hz, 2 H, $\text{CH}=\text{CCH}_2\text{CH}_2$), 1.51 (quin, $J = 7.5$ Hz, 2 H, $\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2$), 1.28 - 1.34 (m, 2 H, $\text{NCH}(\text{CHH})_2$), 1.15 - 1.20 (m, 2 H, $\text{NCH}(\text{CHH})_2$)

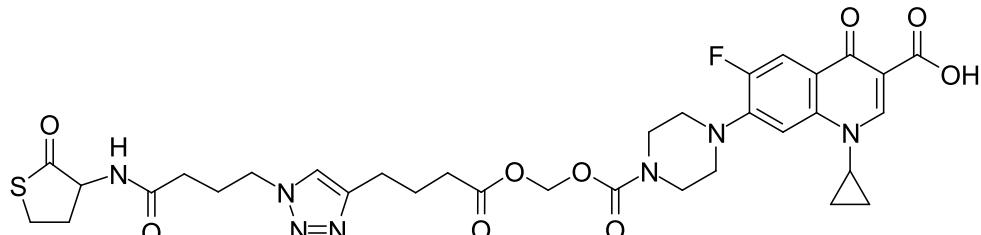
^{13}C NMR (126 MHz, DMSO d₆) δ / ppm = 205.6 ($\text{SC}(\text{=O})$), 176.4 ($\text{C}(\text{=O})\text{CC}(\text{=O})\text{OH}$), 171.4 ($\text{NHC}(\text{=O})$), 166.0 ($\text{C}(\text{=O})\text{OH}$), 153.1 (d, $J = 249.3$ Hz, *ortho* to F), 148.0 ($\text{CH}=\text{CC}(\text{=O})\text{OH}$), 146.9 ($\text{CH}=\text{CCH}_2$), 145.3 (d, $J = 10.1$ Hz, *ipso* to piperazine), 139.2 (*para* to F), 121.8 ($\text{CH}=\text{CCH}_2$), 118.6 (d, $J = 7.7$ Hz, *para* to piperazine), 111.0 (d, $J = 23.3$ Hz, *ortho* to C=O and *ortho* to F), 106.7 ($\text{CC}(\text{=O})\text{OH}$), 106.4 (d, $J = 2.9$ Hz, *meta* to C=O and *meta* to F), 58.2 ($\text{SC}(\text{=O})\text{CHNH}$), 57.4 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 52.4 ($\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2)\text{CH}_2$), 49.5 ($\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)\text{CH}_2\text{CH}_2$), 49.5 ($\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)\text{CH}_2\text{CH}_2$), 48.6 ($\text{CH}_2\text{NCH}=\text{C}$), 35.9 ($\text{NCH}(\text{CH}_2)_2$), 31.9 ($\text{NHC}(\text{=O})\text{CH}_2$), 30.1 (CH_2CHNH), 26.9 ($\text{CH}=\text{CCH}_2\text{CH}_2$), 26.8 (SCH_2), 25.9 ($\text{NHC}(\text{=O})\text{CH}_2\text{CH}_2$), 25.8 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2$), 25.0 ($\text{CH}=\text{CCH}_2$), 7.6 ($\text{NCH}(\text{CH}_2)_2$)

^{19}F NMR (376.45 MHz, MeOD) δ / ppm = -124.9 (s, ciprofloxacin F)

HRMS (ESI⁺) m/z / Da = 640.2739, [M+H]⁺ found, [C₃₁H₃₉FN₇O₅S]⁺ requires 640.2712

The compound has not been reported previously.

5.39 1-Cyclopropyl-6-fluoro-4-oxo-7-((4-((4-((1-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)-1*H*-1,2,3-triazol-4-yl)butanoyl)oxy)methoxy)carbonyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 114



1-Cyclopropyl-6-fluoro-7-((4-((hex-5-ynoyloxy)methoxy)carbonyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **166** (203 mg, 0.407 mmol, 1 eq.), 4-azido-*N*-(2-oxotetrahydrothiophen-3-yl)butanamide **112** (92.8 mg, 0.407 mmol, 1 eq.), CuI (40 mg, 0.190 mmol, 0.5 eq.) and DIPEA (0.356 ml, 0.264 mg, 2.04 mmol, 5 eq.) were stirred in CH₂Cl₂ (18.6 ml) at r.t. under Ar for 3 h. The mixture was filtered and the filtrate was dry-loaded onto SiO₂ and purified by column chromatography (SiO₂, 5-10 % MeOH/CH₂Cl₂). **114** was obtained as pale brown/yellow amorphous solid (14.7 mg, 20.2 μmol , 5.0 %).

TLC R_f = 0.40 (5 % CH₂Cl₂/MeOH)

IR (neat) ν_{max} / cm⁻¹ = 3054.9 (C-H), 1715.8 (carboxylic acid C=O and ester C=O), 1696.2 (carbamate C=O and thiolactone C=O), 1651.2 (amide C=O), 1629.2 (quinolone C=O)

^1H NMR (400 MHz, DMSO d₆) δ / ppm = 15.16 (br s, 1 H, $\text{C}(\text{=O})\text{OH}$), 8.65 (s, 1 H, *ortho* to C=O),

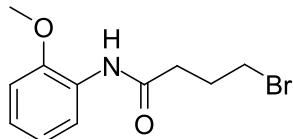
8.21 (d, $J = 8.5$ Hz, 1 H, NH), 7.89 (d, $J = 13.1$ Hz, 1 H, *ortho* to F), 7.85 (s, 1 H, CH=CCH₂), 7.57 (d, $J = 7.4$ Hz, 1 H, *meta* to F), 5.74 (s, 1 H, OCH₂O), 4.58 (ddd, $J = 12.6, 8.1, 7.2$ Hz, 1 H, CHNH), 4.30 (t, $J = 6.9$ Hz, 2 H, C(=O)CH₂CH₂CH₂N), 3.80 (tt, $J = 6.9, 3.6$ Hz, 1 H, NCH(CH₂)₂), 3.62 (br t, $J = 5.2$ Hz, 4 H, C(=O)N(CH₂)CH₂), 3.38 (td, $J = 11.4, 5.5$ Hz, 1 H, SCHH), 3.34 (br. s, 4 H, C(=O)N(CH₂CH₂)CH₂CH₂), 3.27 (ddd, $J = 11.0, 6.9, 1.6$ Hz, 1 H, SCHH), 2.64 (t, $J = 7.6$ Hz, 2 H, CH=CCH₂), 2.44 (t, $J = 7.5$ Hz, 2 H, CH₂C(=O)O), 2.40 (dddd, $J = 12.3, 6.8, 5.4, 1.4$ Hz, 1 H, SCH₂CHH), 2.12 (t, $J = 7.8$ Hz, 1 H, NHC(=O)CHH), 2.12 (t, $J = 6.8$ Hz, 1 H, NHC(=O)CHH), 1.98 - 2.07 (m, 3 H, SCH₂CHH and NHC(=O)CH₂CH₂), 1.86 (quin, $J = 7.5$ Hz, 2 H, CH=CCH₂CH₂), 1.29 - 1.36 (m, 2 H, NCH(CHH)₂), 1.14 - 1.21 (m, 2 H, NCH(CHH)₂)

¹³C NMR (101 MHz, DMSO d₆) δ / ppm = 205.5 (SC(=O)), 176.4 (C(=O)CC(=O)OH), 171.8 (C(=O)OCH₂O), 171.3 (NHC(=O)), 165.9 (C(=O)OH), 152.8 (d, $J = 249.7$ Hz, *ipso* to F), 152.9 (OC(=O)N), 148.1 (CH=CC(=O)OH), 146.0 (CH=CCH₂), 144.9 (d, $J = 9.6$ Hz, *ipso* to piperazine), 139.1 (para to F), 122.0 (CH=CCH₂), 118.9 (d, $J = 7.5$ Hz, *para* to piperazine), 111.0 (d, $J = 23.5$ Hz, *ortho* to C=O and *ortho* to F), 106.8 (CC(=O)OH, and *meta* to C=O and *meta* to F), 80.3 (OCH₂O), 58.2 (CHNH), 49.1 (C(=O)N(CH₂CH₂)CH₂CH₂), 49.1 (C(=O)N(CH₂CH₂)CH₂CH₂), 48.6 (C(=O)CH₂CH₂CH₂N), 43.4 (N(CH₂)CH₂), 43.0 (N(CH₂)CH₂), 35.9 (NCH(CH₂)₂), 32.7 (CH=CCH₂CH₂CH₂C(=O)), 31.8 (NHC(=O)CH₂), 30.1 (SCH₂CH₂), 26.8 (SCH₂), 25.8 (C(=O)CH₂CH₂CH₂N), 24.2 (CH=CCH₂CH₂CH₂C(=O)), 24.0 (CH=CCH₂CH₂CH₂C(=O)), 7.6 (NCH(CH₂)₂)

HRMS (ESI⁺) m/z / Da = 728.2502, [M+H]⁺ found, [C₃₃H₃₉FN₇O₉S]⁺ requires 728.2503

The compound has not been reported previously.

5.40 4-Bromo-N-(2-methoxyphenyl)butanamide 116



2-Methoxyaniline **115** (9.12 ml, 10.0 g, 81.2 mmol, 1 eq.) and NaHCO₃ (8.19 g, 97.4 mmol, 1.2 eq.) were dissolved in water (100 ml) and CH₂Cl₂ (100 ml). The mixture was cooled to 0 °C and 4-bromobutyryl chloride **64** (9.40 ml, 15.1 g, 81.2 mmol, 1 eq.) was added dropwise over 15 min. The mixture was stirred at 0 °C for 1.5 h, then the aqueous layer was removed. The organic layer was dried with MgSO₄ and purified by column chromatography (SiO₂, 5-25 % EtOAc/P.E.). The combined pure fractions were dried with MgSO₄ and evaporated under reduced pressure. **116** was obtained as an initially colourless liquid which slowly turned blue then black if left out on the bench (11.0 g, 40.6 mmol, 50.0 %).

TLC R_f = 0.16 (10 % EtOAc/P.E.)

IR (neat) ν_{max} / cm⁻¹ = 3410.2 (N-H), 3313.4 (N-H), 2961.6 (C-H), 2939.5 (C-H), 2902.5 (C-H), 1676.4 (amide C=O)

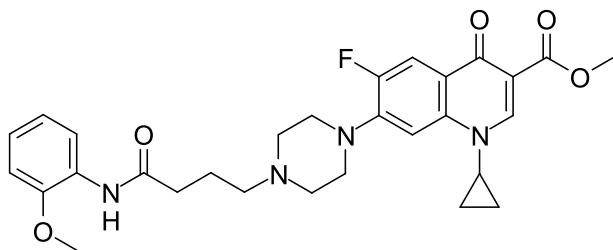
¹H NMR (400 MHz, CDCl₃ d₁) δ / ppm = 8.32 (dd, $J = 8.0, 1.7$ Hz, 1 H, *ortho* to NH), 7.85 (br s, 1 H, NH), 7.02 (td, $J = 7.9, 1.7$ Hz, 1 H, *para* to NH), 6.93 (td, $J = 7.7, 1.4$ Hz, 1 H, *para* to OCH₃), 6.85 (dd, $J = 8.1, 1.5$ Hz, 1 H, *ortho* to OCH₃), 3.85 (s, 3 H, CH₃), 3.50 (t, $J = 6.4$ Hz, 2 H, CH₂Br), 2.56 (t, $J = 7.1$ Hz, 2 H, C(=O)CH₂), 2.25 (quin, $J = 6.7$ Hz, 2 H, C(=O)CH₂CH₂)

¹³C NMR (101 MHz, CDCl₃ d₁) δ / ppm = 169.4 (C(=O)), 147.6 (*ipso* to OCH₃), 127.2 (*ipso* to NH), 123.5 (*para* to NH), 120.7 (*para* to OCH₃), 119.6 (*ortho* to NH and *meta* to OCH₃), 109.8 (*ortho* to OCH₃ and *meta* to NH), 55.5 (CH₃), 35.4 (C(=O)CH₂), 33.1 (CH₂Br), 27.9 (C(=O)CH₂CH₂)

HRMS (ESI⁺) *m/z* / Da = 272.0287, [M+H]⁺ found, [C₁₁H₁₅BrNO₂]⁺ requires 272.0286

The compound has not been reported previously.

5.41 Methyl 1-cyclopropyl-6-fluoro-7-(4-((2-methoxyphenyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 117



Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate **108** (500 mg, 1.45 mmol, 1 eq.), 4-bromo-*N*-(2-methoxyphenyl)butanamide **116** (788 mg, 2.90 mmol, 2 eq.), DIPEA (1.28 ml, 950 mg, 7.35 mmol, 5 eq.), NaI (275 mg, 1.83 mmol, 1.3 eq.) and acetonitrile (10 ml) were stirred in a microwave reactor at 100 °C for 4 h. The mixture was dry-loaded onto SiO₂ and purified by column chromatography (SiO₂, 4 % MeOH/CH₂Cl₂). The combined pure fractions were dried with MgSO₄ and evaporated under reduced pressure. **117** was obtained as a bright pink amorphous solid (79.7 mg, 0.149 mmol, 10.2 %).

TLC *R_f* = 0.40 (10 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 2947.1 (C-H), 2833.7 (C-H), 1718.9 (ester C=O), 1685.3 (amide C=O), 1617.3 (quinolone C=O)

¹H NMR (400 MHz, CDCl₃ d₁) δ / ppm = 8.48 (s, 1 H, *ortho* to C(=O)OCH₃), 8.36 (d, *J* = 7.9 Hz, 1 H, *ortho* to NH), 7.87 - 7.99 (m, 2 H, *ortho* to F and NH), 7.19 (d, *J* = 6.5 Hz, 1 H, *meta* to F), 7.01 (t, *J* = 7.5 Hz, 1 H, *para* to NH), 6.93 (t, *J* = 7.7 Hz, 1 H, *para* to OCH₃), 6.85 (d, *J* = 7.9 Hz, 1 H, *ortho* to OCH₃), 3.88 (s, 3 H, C(=O)OCH₃), 3.85 (s, 3 H, aromatic OCH₃), 3.41 (tt, *J* = 6.9, 4.0 Hz, 1 H, NCH(CH₂)₂), 3.25 (br t, *J* = 5.0, 5.0 Hz, 4 H, C(=O)CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.67 (br t, *J* = 5.0 Hz, 4 H, C(=O)CH₂CH₂CH₂N(CH₂CH₂), 2.53 (t, *J* = 7.0 Hz, 2 H, C(=O)CH₂CH₂CH₂N), 2.47 (t, *J* = 7.1 Hz, 2 H, C(=O)CH₂CH₂CH₂N), 1.97 (quin, *J* = 6.8 Hz, 2 H, C(=O)CH₂CH₂CH₂N), 1.25 - 1.33 (m, 2 H, NCH(CHH)₂), 1.07 - 1.14 (m, 2 H, NCH(CHH)₂)

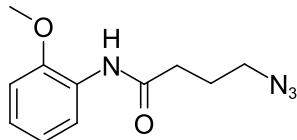
¹³C NMR (101 MHz, CDCl₃ d₁) δ / ppm = 172.9 (C(=O)CC(=O)OCH₃), 170.8 (NH₂C(=O)), 166.2 (C(=O)OCH₃), 153.3 (d, *J* = 248.0 Hz, *ipso* to F), 148.2 (C=CC(=O)OCH₃), 147.6 (*ipso* to OCH₃), 144.4 (d, *J* = 10.4 Hz, *ipso* to piperazine), 137.9 (*para* to F), 127.6 (*ipso* to NH), 123.4 (*para* to NH), 122.7 (d, *J* = 7.8 Hz, *para* to piperazine), 121.0 (*para* to OCH₃), 119.7 (*ortho* to NH and *meta* to OCH₃), 113.0 (d, *J* = 22.5 Hz, *ortho* to C=O and *ortho* to F), 109.8 (*ortho* to OCH₃ and *meta* to NH, and CC(=O)OCH₃), 104.7 (*meta* to C=O and *meta* to F), 57.2 (CH₂CH₂CH₂N), 55.6 (aromatic OCH₃), 52.7 (CH₂CH₂CH₂N(CH₂CH₂), 51.9 (C(=O)OCH₃), 49.8 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 49.8 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 35.5 (CH₂

CH₂CH₂N), 34.5 (NCH(CH₂)₂), 22.3 (CH₂CH₂CH₂N), 8.0 (NCH(CH₂)₂)

HRMS (ESI⁺) *m/z* / Da = 537.2523, [M+H]⁺ found, [C₂₉H₃₄FN₄O₅]⁺ requires 537.2513

The compound has not been reported previously.

5.42 4-Azido-*N*-(2-methoxyphenyl)butanamide 118



4-Bromo-*N*-(2-methoxyphenyl)butanamide **116** (2.05 g, 7.51 mmol, 1 eq.) and NaN₃ (1.17 g, 18.0 mmol, 2.4 eq.) were refluxed in acetonitrile (100 ml) for 2 h. The mixture was cooled and filtered, and the filtrate was dry-loaded onto SiO₂ and purified by column chromatography using a Combiflash (SiO₂, 8-14 % then held at 14 % EtOAc/P.E.). **118** was obtained as an initially colourless liquid which slowly turned blue then black if left out on the bench (0.469 g, 2.00 mmol, 26.7 %).

TLC *R_f* = 0.20 (25 % EtOAc/P.E.)

IR (neat) ν_{max} / cm⁻¹ = 3419.7 (N-H), 3329.6 (N-H), 2094.8 (azide), 1672.3 (amide C=O)

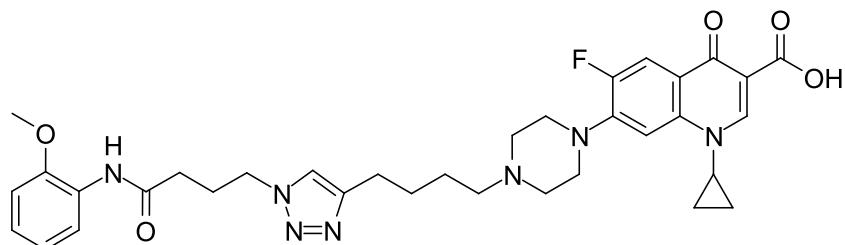
¹H NMR (400 MHz, CDCl₃ d₁) δ / ppm = 8.32 (dd, *J* = 7.9, 1.0 Hz, 1 H, *ortho* to NH), 7.86 (br s, 1 H, NH), 7.00 (td, *J* = 7.5, 1.5 Hz, 1 H, *para* to NH), 6.90 (td, *J* = 7.7, 1.1 Hz, 1 H, *para* to OCH₃), 6.83 (dd, *J* = 8.1, 1.4 Hz, 1 H, *ortho* to OCH₃), 3.81 (s, 3 H, CH₃), 3.33 (t, *J* = 6.7 Hz, 2 H, CH₂Br), 2.42 (t, *J* = 7.2 Hz, 2 H, C(=O)CH₂), 1.94 (quin, *J* = 6.9 Hz, 2 H, C(=O)CH₂CH₂)

¹³C NMR (101 MHz, CDCl₃ d₁) δ / ppm = 169.5 (C(=O)), 147.6 (*ipso* to OCH₃), 127.1 (*ipso* to NH), 123.4 (*para* to NH), 120.5 (*para* to OCH₃), 119.5 (*ortho* to NH and *meta* to OCH₃), 109.6 (*ortho* to OCH₃ and *meta* to NH), 55.2 (CH₃), 50.3 (CH₂N₃), 33.9 (C(=O)CH₂), 24.3 (C(=O)CH₂CH₂)

HRMS (ESI⁺) *m/z* / Da = 257.1010, [M+H]⁺ found, [C₁₁H₁₄N₄NaO₂]⁺ requires 257.1014

The data are consistent with the literature.¹⁷⁹

5.43 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((2-methoxyphenyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 119



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **76** (24.1 mg, 58.6 μ mol, 1 eq.) and 4-azido-*N*-(2-methoxyphenyl)butanamide **118** (13.7 mg, 58.5 μ mol, 1 eq.) were dissolved in water (3 ml), *t*-BuOH (9 ml) and CH₂Cl₂ (9 ml), and the mixture was degassed by bubbling through N₂. A solution of CuSO₄ and THPTA (117 μ l, 5.85 μ mol, 0.1 eq., 50 mM, aq.) was added, followed by a solution of sodium ascorbate (234 μ l, 11.7 μ mol, 0.2 eq., 50 mM, aq.). The mixture was stirred at room temperature under argon for 16 h. Water (25 ml), CH₂Cl₂ (25 ml) and MeOH (5 ml) were added and the organic layer was separated off, dry-loaded onto SiO₂ and purified by column chromatography using a CombiFlash (SiO₂, 3-23 % MeOH/CH₂Cl₂). The combined pure fractions were dried with MgSO₄ and evaporated under reduced pressure. **119** was obtained as a clear amorphous solid (14.7 mg, 22.8 μ mol, 39.0 %).

TLC R_f = 0.28 (10 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 2926.5 (C-H), 2846.6 (C-H), 1723.4 (carboxylic acid C=O), 1682.0 (amide C=O), 1625.8 (quinolone C=O), 1612.8 (triazole)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 15.05 (br s, 1 H, C(=O)OH), 8.76 (s, 1 H, *ortho* to C(=O)OH), 8.31 (dd, J = 8.0, 1.7 Hz, 1 H, *ortho* to NH), 8.00 (d, J = 13.0 Hz, 1 H, *ortho* to F), 7.83 (br s, 1 H, NH), 7.37 (s, 1 H, CH=CCH₂), 7.35 (d, J = 7.2 Hz, 1 H, *meta* to F), 7.04 (td, J = 7.7, 1.7 Hz, 1 H, *para* to NH), 6.95 (td, J = 7.8, 1.5 Hz, 1 H, *para* to OCH₃), 6.88 (dd, J = 8.1, 1.4 Hz, 1 H, *ortho* to OCH₃), 4.47 (t, J = 6.7 Hz, 2 H, C(=O)CH₂CH₂CH₂N), 3.88 (s, 3 H, CH₃), 3.54 (tt, J = 6.9, 4.0 Hz, 1 H, NCH(CH₂)₂), 3.35 (br t, J = 4.7 Hz, 4 H, CH=CCH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.76 (t, J = 7.5 Hz, 2 H, CH=CCH₂), 2.66 (t, J = 4.7 Hz, 4 H, CH=CCH₂CH₂CH₂N(CH₂)CH₂), 2.47 (t, J = 7.3 Hz, 2 H, CH=CCH₂CH₂CH₂N), 2.44 (t, J = 6.8 Hz, 2 H, C(=O)CH₂CH₂CH₂N), 2.32 (quin, J = 6.7 Hz, 2 H, C(=O)CH₂CH₂CH₂N), 1.75 (quin, J = 7.6 Hz, 2 H, CH=CCH₂CH₂CH₂N), 1.61 (quin, J = 7.5 Hz, 2 H, CH=CCH₂CH₂CH₂N), 1.35 - 1.42 (m, 2 H, NCH(CHH)₂), 1.17 - 1.22 (m, 2 H, NCH(CHH)₂)

¹³C NMR (101 MHz, CDCl₃) δ / ppm = 177.1 (C(=O)CC(=O)OH), 169.5 (NH \underline{C} (=O)), 167.0 (C(=O)OH), 153.7 (d, J = 251.4 Hz, *ipso* to F), 148.1 (CH=CCH₂), 147.8 (*ipso* to OCH₃), 147.3 (C=CC(=O)OH), 145.9 (d, J = 10.4 Hz, *ipso* to piperazine), 139.1 (*para* to F), 127.3 (*ipso* to NH), 123.9 (*para* to NH), 121.0 (*para* to OCH₃), 120.9 (CH=CCH₂), 119.7 (*para* to piperazine, and *ortho* to NH and *meta* to OCH₃), 112.4 (d, J = 23.4 Hz, *ortho* to C=O and *ortho* to F), 109.9 (*ortho* to OCH₃ and *meta* to NH), 108.1 (C(=O)OH), 104.7 (*meta* to C=O and *meta* to F), 58.1 (CH=CCH₂CH₂CH₂N), 55.6 (CH₃), 52.8 (CH=CCH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 49.8 (CH=CCH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 49.8 (CH=CCH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 49.1 (C(=O)CH₂CH₂CH₂N), 35.2 (NCH(CH₂)₂), 33.8 (C(=O)CH₂CH₂CH₂N), 27.3 (CH=CCH₂CH₂CH₂N), 26.4 (CH=CCH₂CH₂CH₂N), 26.0 (C(=O)CH₂CH₂CH₂N), 25.5 (CH=CCH₂CH₂CH₂N), 8.2 (NCH

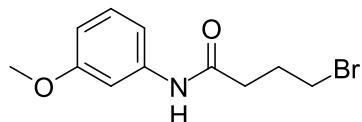
$(\underline{\text{CH}_2})_2$

^{19}F NMR (376.45 MHz, CDCl_3) δ / ppm = -120.7 (s, ciprofloxacin F)

HRMS (ESI $^+$) m/z / Da = 646.3132, $[\text{M}+\text{H}]^+$ found, $[\text{C}_{34}\text{H}_{41}\text{FN}_7\text{O}_5]^+$ requires 646.3153

The compound has not been reported previously.

5.44 4-Bromo-*N*-(3-methoxyphenyl)butanamide 121



3-Methoxyaniline **120** (3.04 ml, 3.33 g, 27.1 mmol, 1 eq.) and NaHCO_3 (2.73 g, 32.5 mmol, 1.2 eq.) were dissolved in water (30 ml) and CH_2Cl_2 (30 ml). The mixture was cooled to 0 °C and 4-bromobutyryl chloride **64** (3.13 ml, 5.03 g, 27.1 mmol, 1 eq.) was added dropwise over 5 min. The mixture was stirred at 0 °C for 1 h, then the aqueous layer was removed. The organic layer was dry-loaded onto SiO_2 and purified by column chromatography using a CombiFlash (SiO_2 , 0-100 % EtOAc/P.E.). The combined pure fractions were dried with MgSO_4 and evaporated under reduced pressure. **121** was obtained as a pale pink amorphous solid (3.66 g, 13.5 mmol, 49.6 %).

TLC R_f = 0.18 (25 % EtOAc/P.E.)

IR (neat) ν_{max} / cm^{-1} = 1670.9 (amide C=O)

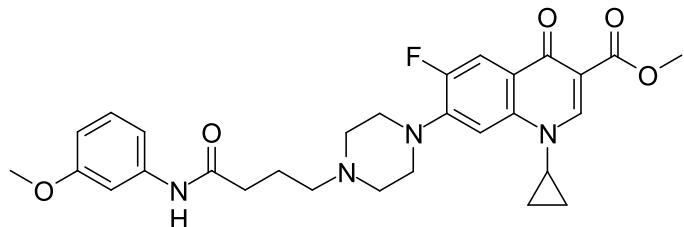
^1H NMR (400 MHz, CDCl_3 d₁) δ / ppm = 8.45 (s, 1 H, NH), 7.27 (t, J = 2.2 Hz, 1 H, *ortho* to OCH_3 and *ortho* to NH), 7.14 (t, J = 8.1 Hz, 1 H, *meta* to OCH_3 and *meta* to NH), 7.02 (d, J = 8.3 Hz, 1 H, *para* to OCH_3), 6.62 (dd, J = 8.2, 2.1 Hz, 1 H, *para* to NH), 3.71 (s, 3 H, $\underline{\text{CH}_3}$), 3.42 (t, J = 6.5 Hz, 2 H, $\underline{\text{CH}_2\text{Br}}$), 2.51 (t, J = 6.9 Hz, 2 H, C(=O) $\underline{\text{CH}_2}$), 2.19 (quin, J = 6.8 Hz, 2 H, C(=O) $\text{CH}_2\underline{\text{CH}_2}$)

^{13}C NMR (101 MHz, CDCl_3 d₁) δ / ppm = 170.3 ($\underline{\text{C}(=\text{O})}$), 159.9 (*ipso* to OCH_3), 139.0 (*ipso* to NH), 129.5 (*meta* to OCH_3 and *meta* to NH), 112.1 (*para* to OCH_3), 109.9 (*para* to NH), 105.7 (*ortho* to OCH_3 and *ortho* to NH), 55.2 ($\underline{\text{CH}_3}$), 35.3 (C(=O) $\underline{\text{CH}_2}$), 33.2 ($\underline{\text{CH}_2\text{Br}}$), 28.0 (C(=O) $\text{CH}_2\underline{\text{CH}_2}$)

HRMS (ESI $^+$) The compound does not ionise.

The compound has not been reported previously.

5.45 Methyl 1-cyclopropyl-6-fluoro-7-(4-((3-methoxyphenyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 122



Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate **108** (500 mg, 1.45 mmol, 1 eq.), 4-bromo-*N*-(3-methoxyphenyl)butanamide **121** (788 mg, 2.90 mmol, 2 eq.), DIPEA (1.28 ml, 950 mg, 7.35 mmol, 5 eq.), NaI (275 mg, 1.83 mmol, 1.3 eq.) and acetonitrile (10 ml) were stirred in a microwave reactor at 100 °C for 4 h. The mixture was evaporated under reduced pressure and partitioned between CH₂Cl₂ (50 ml) and water (50 ml). The organic layer was separated off and the aqueous layer was extracted again with CH₂Cl₂ (50 ml). The combined organic layers were dried with MgSO₄ and purified by column chromatography (SiO₂, 0-4 % MeOH/CH₂Cl₂). The combined pure fractions were dried with MgSO₄ and evaporated under reduced pressure. **122** was obtained as an off-white amorphous solid (81.7 mg, 0.152 mmol, 10.5 %).

TLC R_f = 0.38 (10 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 3270.8 (amide N-H) 2943.8 (C-H), 2817.0 (C-H), 1729.5 (ester C=O), 1682.0 (amide C=O), 1613.5 (quinolone C=O)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 8.56 (s, 1 H, *ortho* to C(=O)OCH₃), 8.06 (d, J = 13.3 Hz, 1 H, *ortho* to F), 8.02 (br s, 1 H, NH), 7.34 (t, J = 1.7 Hz, 1 H, *ortho* to OCH₃ and *ortho* to NH), 7.25 (d, J = 7.0 Hz, 1 H, *meta* to F), 7.20 (t, J = 8.2 Hz, 1 H, *meta* to OCH₃ and *meta* to NH), 6.98 (dd, J = 7.8, 1.7 Hz, 1 H, *para* to OCH₃), 6.65 (dd, J = 8.2, 2.1 Hz, 1 H, *para* to NH), 3.93 (s, 3 H, C(=O)OCH₃), 3.80 (s, 3 H, aromatic OCH₃), 3.42 (tt, J = 6.8, 3.7 Hz, 1 H, NCH(CH₂)₂), 3.31 (br t, J = 4.3 Hz, 4 H, C(=O)CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.73 (br t, J = 4.5 Hz, 4 H, C(=O)CH₂CH₂CH₂N(CH₂)CH₂), 2.58 (t, J = 6.5 Hz, 2 H, C(=O)CH₂CH₂CH₂N), 2.48 (t, J = 6.8 Hz, 2 H, C(=O)CH₂CH₂CH₂N), 2.00 (quin, J = 6.8 Hz, 2 H, C(=O)CH₂CH₂CH₂N), 1.29 - 1.36 (m, 2 H, NCH(CHH)₂), 1.11 - 1.17 (m, 2 H, NCH(CHH)₂)

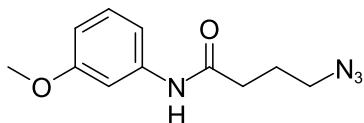
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 173.1 (C(=O)CC(=O)OCH₃), 170.9 (NHC(=O)), 166.3 (C(=O)OCH₃), 160.1 (*ipso* to OCH₃), 153.3 (d, J = 250.1 Hz, *ipso* to F), 148.4 (C=CC(=O)OCH₃), 144.1 (d, J = 10.1 Hz, *ipso* to piperazine), 139.4 (*ipso* to NH), 138.0 (*para* to F), 129.6 (*meta* to NH and *meta* to OCH₃), 123.3 (d, J = 6.4 Hz, *para* to piperazine), 113.4 (d, J = 23.3 Hz, *ortho* to C=O and *ortho* to F), 111.8 (*para* to OCH₃), 110.0 (CC(=O)OCH₃), 109.8 (*para* to NH), 105.5 (*ortho* to OCH₃ and *ortho* to NH), 105.0 (*meta* to C=O and *meta* to F), 57.0 (CH₂CH₂CH₂N), 55.3 (aromatic OCH₃), 52.6 (CH₂CH₂CH₂N(CH₂)CH₂), 52.1 (C(=O)OCH₃), 49.2 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 35.2 (CH₂CH₂CH₂N), 34.6 (NCH(CH₂)₂), 21.7 (CH₂CH₂CH₂N), 8.2 (NCH(CH₂)₂)

¹⁹F NMR (376.45 MHz, MeOD) δ / ppm = -123.5 (s, ciprofloxacin F)

HRMS (ESI⁺) m/z / Da = 537.2500, [M+H]⁺ found, [C₂₉H₃₄FN₄O₅]⁺ requires 537.2513

The compound has not been reported previously.

5.46 4-Azido-*N*-(3-methoxyphenyl)butanamide 123



4-Bromo-*N*-(3-methoxyphenyl)butanamide **121** (2.05 g, 7.51 mmol, 1 eq.) and NaN_3 (1.17 g, 18.0 mmol, 2.4 eq.) were refluxed in acetonitrile (100 ml) for 7 h. The mixture was cooled and filtered, and the filtrate was dry-loaded onto SiO_2 and purified by column chromatography using a Combiflash (SiO_2 , 0-100 % EtOAc/P.E.). The combined pure fractions were dried with MgSO_4 and evaporated under reduced pressure. **123** was obtained as a straw-coloured liquid (0.294 g, 1.25 mmol, 16.7 %).

TLC R_f = 0.37 (50 % EtOAc/P.E.)

IR (neat) ν_{max} / cm^{-1} = 3298.3 (N-H), 2094.7 (azide), 1661.7 (amide C=O)

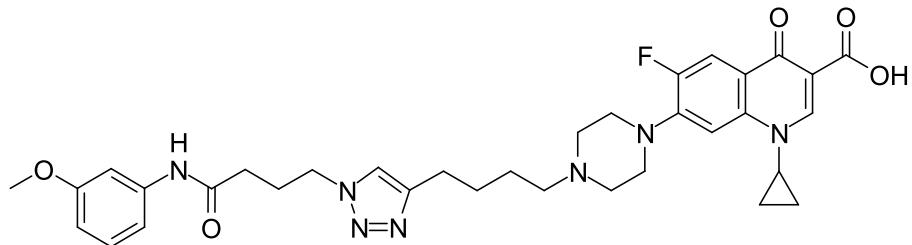
$^1\text{H NMR}$ (400 MHz, MeOD) δ / ppm = 8.63 (br s, 1 H, NH), 7.26 (t, J = 2.3 Hz, 1 H, *ortho* to OCH_3 and *ortho* to NH), 7.15 (t, J = 8.1 Hz, 1 H, *meta* to OCH_3 and *meta* to NH), 7.01 (dd, J = 7.8, 1.6 Hz, 1 H, *para* to OCH_3), 6.63 (dd, J = 8.2, 1.9 Hz, 1 H, *para* to NH), 3.69 (s, 3 H, CH_3), 3.28 (t, J = 6.7 Hz, 2 H, CH_2N_3), 2.39 (t, J = 7.4 Hz, 2 H, $\text{C}(=\text{O})\text{CH}_2$), 1.91 (quin, J = 7.0 Hz, 2 H, $\text{C}(=\text{O})\text{CH}_2\text{CH}_2$)

$^{13}\text{C NMR}$ (101 MHz, MeOD) δ / ppm = 170.8 ($\text{C}(=\text{O})$), 159.6 (*ipso* to OCH_3), 138.9 (*ipso* to NH), 129.2 (*meta* to OCH_3 and *meta* to NH), 112.3 (*para* to OCH_3), 109.5 (*para* to NH), 106.0 (*ortho* to OCH_3 and *ortho* to NH), 54.8 (CH_3), 50.4 (CH_2N_3), 33.6 ($\text{C}(=\text{O})\text{CH}_2$), 24.4 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2$)

HRMS (ESI⁺) The compound does not ionise.

The compound has not been reported previously.

5.47 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((3-methoxyphenyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 124



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **76** (24.1 mg, 58.6 μmol , 1 eq.) and 4-azido-*N*-(3-methoxyphenyl)butanamide **123** (13.7 mg, 58.5 μmol , 1 eq.) were dissolved in water (1 ml), *t*-BuOH (9 ml) and CH_2Cl_2 (10 ml), and the mixture was degassed by bubbling through

N_2 . A solution of CuSO_4 and THPTA (58.5 μl , 5.85 μmol , 0.1 eq. 100 mM, aq.) was added, followed by a solution of sodium ascorbate (117 μl , 11.7 μmol , 0.2 eq., 100 mM, aq.). The mixture was stirred at room temperature under argon for 2 h, then the solvent was removed under reduced pressure. The residue was partitioned between water (15 ml) and CH_2Cl_2 (15 ml), and the aqueous layer was extracted a further four times with CH_2Cl_2 (4×15 ml). The combined organic layers were dried with MgSO_4 , dry-loaded onto SiO_2 and purified by column chromatography (SiO_2 , 0-10 % $\text{MeOH}/\text{CH}_2\text{Cl}_2$). The combined pure fractions were dried with MgSO_4 and evaporated under reduced pressure. **124** was obtained as a clear amorphous solid (1.9 mg, 2.9 μmol , 5.0 %).

TLC $R_f = 0.22$ (10 % $\text{MeOH}/\text{CH}_2\text{Cl}_2$)

IR (neat) ν_{max} / $\text{cm}^{-1} = 2922.8$ (C-H), 2849.5 (C-H), 1725.8 (carboxylic acid C=O), 1684.7 (amide C=O), 1624.5 (quinolone C=O), 1612.2 (triazole)

$^1\text{H NMR}$ (400 MHz, DMSO d₆) δ / ppm = 15.23 (br s, 1 H, C(=O)OH), 9.89 (s, 1 H, NH), 8.66 (s, 1 H, *ortho* to C(=O)OH), 7.90 (d, $J = 13.4$ Hz, 1 H, *ortho* to F), 7.88 (s, 1 H, CH=CCH₂), 7.55 (d, $J = 7.6$ Hz, 1 H, *meta* to F), 7.27 (t, $J = 2.1$ Hz, 1 H, *ortho* to C=O and *ortho* to F), 7.16 (t, $J = 8.1$ Hz, 1 H, *meta* to OCH₃ and *meta* to NH), 7.08 (d, $J = 7.8$ Hz, 1 H, *para* to OCH₃), 6.59 (ddd, $J = 8.1, 2.4, 0.7$ Hz, 1 H, *para* to NH), 4.36 (t, $J = 6.9$ Hz, 2 H, C(=O)CH₂CH₂CH₂N), 3.81 (tt, $J = 6.7, 4.0$ Hz, 1 H, NCH(CH₂)₂), 3.70 (s, 3 H, CH₃), 3.28 - 3.32 (m, 4 H, CH=CCH₂CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.64 (t, $J = 7.5$ Hz, 2 H, CH=CCH₂), 2.56 (m, $J = 4.2, 4.2$ Hz, 4 H, CH=CCH₂CH₂CH₂CH₂N(CH₂)CH₂), 2.38 (t, $J = 7.3$ Hz, 2 H, CH=CCH₂CH₂CH₂N), 2.30 (t, $J = 7.4$ Hz, 2 H, C(=O)CH₂CH₂CH₂N), 2.10 (quin, $J = 7.1$ Hz, 2 H, C(=O)CH₂CH₂N), 1.64 (quin, $J = 7.5$ Hz, 2 H, CH=CCH₂CH₂CH₂N), 1.51 (quin, $J = 7.2$ Hz, 2 H, CH=CCH₂CH₂CH₂N), 1.27 - 1.33 (m, 2 H, NCH(CHH)₂), 1.15 - 1.20 (m, 2 H, NCH(CHH)₂)

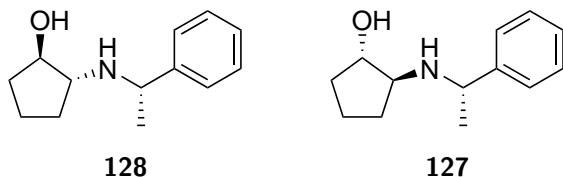
$^{13}\text{C NMR}$ (101 MHz, DMSO d₆) δ / ppm = 176.3 (C(=O)CC(=O)OH), 170.1 (NHC(=O)), 165.9 (C(=O)OH), 159.4 (*ipso* to OCH₃), 153.0 (d, $J = 248.6$ Hz, *ipso* to F), 148.0 (CH=CCH₂), 146.9 (C=CC(=O)OH), 145.2 (d, $J = 10.7$ Hz, *ipso* to piperazine), 140.3 (*para* to F), 139.2 (*ipso* to NH), 129.4 (*meta* to OCH₃ and *meta* to NH), 121.7 (CH=CCH₂), 118.5 (d, $J = 7.5$ Hz, *para* to piperazine), 111.3 (*para* to OCH₃), 110.9 (d, $J = 22.4$ Hz, *ortho* to C=O and *ortho* to F), 108.4 (*para* to NH), 106.7 (CC(=O)OH), 106.3 (*meta* to C=O and *meta* to F), 104.8 (*ortho* to OCH₃ and *ortho* to NH), 57.3 (CH=CCH₂CH₂CH₂N), 54.9 (CH₃), 52.4 (CH=CCH₂CH₂CH₂N(CH₂)CH₂), 49.5 (CH=CCH₂CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 49.4 (CH=CCH₂CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 48.7 (C(=O)CH₂CH₂N), 35.8 (NCH(CH₂)₂), 32.9 (C(=O)CH₂CH₂N), 26.8 (CH=CCH₂CH₂CH₂N), 25.7 (CH=CCH₂CH₂N), 25.5 (C(=O)CH₂CH₂CH₂N), 24.9 (CH=CCH₂CH₂CH₂N), 7.6 (NCH(CH₂)₂)

$^{19}\text{F NMR}$ (376.45 MHz, DMSO d₆) δ / ppm = -121.5 (s, ciprofloxacin F)

HRMS (ESI⁺) m/z / Da = 646.3159, [M+H]⁺ found, [C₃₄H₄₁FN₇O₅]⁺ requires 646.3153

The compound has not been reported previously.

5.48 (1*S*,2*S*)-2-(((*S*)-1-Phenylethyl)amino)cyclopentan-1-ol 127 and (1*R*,2*R*)-2-(((*S*)-1-phenylethyl)amino)cyclopentan-1-ol 128



(S)-1-Phenylethan-1-amine **126** (7.85 ml, 7.38 g, 60.9 mmol, 1 eq.) was dissolved in CH_2Cl_2 (50 ml) and stirred rapidly at 0 °C. A solution of AlMe_3 (31 ml, 2.0 M in heptane, 60.9 mmol) was added dropwise and the mixture was stirred at 0 °C for 1 h. A solution of cyclohexene oxide **125** (5.71 ml, 5.50 g, 65.4 mmol, 1.1 eq.) in CH_2Cl_2 (50 ml) was then added dropwise, and the mixture was stirred at 0 °C for a further 3 h, followed by 48 h at r.t.. The mixture was cooled to 0 °C and NaF (11 g, 262 mmol, 4.3 eq.) was added portionwise, followed by water (7.00 ml, 7.00 g, 389 mmol, 6.4 eq.) and CH_2Cl_2 (50 ml). The suspension was allowed to warm to r.t. and stirred for 1 h, then filtered through Celite and washed with CH_2Cl_2 (500 ml). The filtrate was dried with K_2CO_3 , concentrated under reduced pressure and purified by column chromatography (SiO_2 , 20:5:1 hexane:EtOAc:TEA). **128** was obtained as a pale yellow oil (4.08 g, 19.9 mmol, 32.6 %). **127** was obtained as pale yellow crystals (4.48 g, 21.8 mmol, 35.8 %).

(1*S*,2*S*)-2-(((*S*)-1-Phenylethyl)amino)cyclopentan-1-ol 127

TLC $R_f = 0.36$ (15:5:1 hexane:EtOAc:TEA)

mp T / °C = 66-71.5 (hexane, EtOAc, TEA)

IR (neat) ν_{max} / cm⁻¹ = 3150.0 (br, O-H), 2950.9 (C-H), 2868.2 (C-H)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 7.28 - 7.34 (m, 4 H, *ortho* and *meta* to CHCH₃), 7.20 - 7.26 (m, 1 H, *para* to CHCH₃), 3.86 (q, J = 6.6 Hz, 1 H, CHCH₃), 3.85 (q, J = 6.6 Hz, 1 H, CHO_H), 2.83 (td, J = 7.6, 5.7 Hz, 1 H, CHNH), 1.85 - 1.97 (m, 1 H, CHHCHOH), 1.77 (dtd, J = 12.9, 7.9, 4.9 Hz, 1 H, CHHCHNH), 1.55 - 1.68 (m, 2 H, CH₂CH₂CHOH), 1.47 - 1.55 (m, 1 H, CHHCHOH), 1.36 (d, J = 6.6 Hz, 3 H, CH₃), 1.12 (dq, J = 12.7, 8.1 Hz, 1 H, CHHCHNH)

¹³C NMR (101 MHz, CDCl₃) δ / ppm = 145.61 (*ipso* to CHCH₃), 128.08 (*meta* to CHCH₃), 126.61 (*para* to CHCH₃), 126.33 (*ortho* to CHCH₃), 77.43 (CHOH), 64.45 (CHNH), 56.62 (CHCH₃), 32.01 (CH₂CHOH), 30.56 (CH₂CHNH), 23.30 (CH₃), 20.06 (CH₂CH₂CHOH)

HRMS (ESI⁺) m/z / Da = 206.1553, [M+H]⁺ found, [C₁₃H₂₀NO]⁺ requires 206.1545

$[\alpha]_D^{20} / {}^\circ 10^{-1} \text{cm}^2 \text{g}^{-1} = -23.9$, lit. = -22.1 ($c / \text{g(100 ml)}^{-1} = 0.96$, MeOH)

(1*R*,2*R*)-2-(((*S*)-1-Phenylethyl)amino)cyclopentan-1-ol 128

TLC $R_f = 0.25$ (15:5:1 hexane:EtOAc:TEA)

IR (neat) ν_{max} / cm⁻¹ = 3300.0 (br, O-H), 2959.7 (C-H), 2870.1 (C-H)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 7.28 - 7.38 (m, 4 H, *ortho* and *meta* to CHCH₃), 7.21 - 7.28 (m, 1 H, *para* to CHCH₃), 3.83 (q, J = 6.6 Hz, 1 H, CHCH₃), 3.78 (q, J = 7.0 Hz, 1 H, CHOH), 2.62 (dt, J = 8.2, 7.2 Hz, 1 H, CHNH), 1.97 (quin, J = 6.7 Hz, 1 H, CH₂CHNH), 1.90 (quin, J = 6.9 Hz, 1 H, CH₂CHOH), 1.56 - 1.68 (m, CH₂CH₂CHOH), 1.43 (dq, J = 12.5, 8.0 Hz, 1 H, CH₂CHOH), 1.37 (d, J = 6.6 Hz, 3 H, CH₃), 1.25 - 1.36 (m, 1 H, CH₂CHNH)

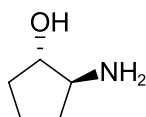
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 144.75 (*ipso* to CHCH₃), 128.26 (*meta* to CHCH₃), 126.72 (*para* to CHCH₃), 126.30 (*ortho* to CHCH₃), 77.65 (CHOH), 63.38 (CHNH), 56.20 (CHCH₃), 31.74 (CH₂CHOH), 29.22 (CH₂CHNH), 24.58 (CH₃), 19.57 (CH₂CH₂CHOH)

HRMS (ESI⁺) m/z / Da = 206.1554, [M+H]⁺ found, [C₁₃H₂₀NO]⁺ requires 206.1545

$[\alpha]_D^{20} / {}^\circ 10^{-1} \text{cm}^2 \text{g}^{-1} = -92.8$, lit. = -76.8 (c / g(100 ml)⁻¹ = 1.19, MeOH)

The compounds have been synthesised previously,^{167,168} but NMR data were not published. The enantiomers of both compounds have also been synthesised previously, and the ¹H NMR data for these are consistent with the the above data.¹⁶⁹

5.49 (1*S*,2*S*)-2-Aminocyclopentan-1-ol 129



(1*S*,2*S*)-2-((*S*)-1-Phenylethyl)amino)cyclopentan-1-ol **127** (3.00 g, 14.6 mmol, 1 eq.), Pd(OH)₂ (20 wt. % on C, moistened with 50 wt. % water, 0.5 g, 0.356 mmol, 0.025 eq.) and MeOH (50 ml) were stirred in a Paar hydrogenator at r.t. and 2.5 atm for 2 days. The mixture was then filtered through Celite and evaporated under reduced pressure. **129** was obtained as a yellow oil (1.48 g, 14.6 mmol, 100 %).

TLC R_f = 0.10 (10 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 3300.0 (O-H), 2969.2 (C-H), 2872.7 (C-H)

¹H NMR (400 MHz, MeOD) δ / ppm = 3.77 (ddd, J = 6.6, 6.2, 5.6, 1 H, CHOH), 3.00 (td, J = 7.4, 5.6 Hz, 1 H, CHNH₂), 2.00 (dtd, J = 13.0, 7.7, 5.6 Hz, 1 H, CHHCHNH₂), 1.97 (ddt, J = 13.0, 8.7, 6.4 Hz, 1 H, CHHCHOH), 1.64 - 1.77 (m, 2 H, CH₂CH₂CHOH), 1.53 (ddt, J = 13.0, 9.5, 6.2 Hz, 1 H, CHHCHOH), 1.37 (ddt, J = 12.8, 8.5, 7.7 Hz, 1 H, CHHCHNH₂)

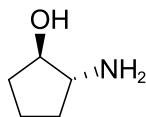
¹³C NMR (101 MHz, MeOD) δ / ppm = 80.6 (CHOH), 60.7 (CHNH₂), 33.2 (CH₂CHOH), 32.2 (CH₂CHNH₂), 21.2 (CH₂CH₂CHOH)

HRMS (ESI⁺) m/z / Da = 102.0915, [M+H]⁺ found, [C₅H₁₂NO]⁺ requires 102.0913

$[\alpha]_D^{20} / {}^\circ 10^{-1} \text{cm}^2 \text{g}^{-1} = 33.4$, lit. = 29.7 (c / g(100 ml)⁻¹ = 0.5, EtOH)

The data are consistent with the literature.^{168,180}

5.50 (1*R*,2*R*)-2-Aminocyclopentan-1-ol 130



(1*R*,2*R*)-2-(((*S*)-1-Phenylethyl)amino)cyclopentan-1-ol **128** (3.90 g, 19.0 mmol, 1 eq.), Pd(OH)₂ (20 wt. % on C, moistened with 50 wt. % water, 1 g, 0.712 mmol, 0.04 eq.) and MeOH (50 ml) were stirred in a Paar hydrogenator at r.t. and 3 atm for 2 days. The mixture was then filtered through Celite and evaporated under reduced pressure. **130** was obtained as a yellow oil (1.92 g, 19.0 mmol, 100 %).

TLC R_f = 0.10 (10 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 3300.0 (br, O-H), 2958.3 (C-H), 2871.5 (C-H)

¹H NMR (400 MHz, MeOD) δ / ppm = 3.77 (ddd, *J* = 6.6, 6.2, 5.6, 1 H, CH_{OH}), 3.00 (td, *J* = 7.3, 5.6 Hz, 1 H, CH₂NH₂), 2.00 (dtd, *J* = 13.0, 7.7, 5.6 Hz, 1 H, CH₂CH₂NH₂), 1.97 (ddt, *J* = 13.0, 8.7, 6.6 Hz, 1 H, CH₂CHOH), 1.63 - 1.77 (m, 2 H, CH₂CH₂CHOH), 1.53 (ddt, *J* = 13.0, 9.5, 6.2 Hz, 1 H, CH₂CHOH), 1.37 (ddt, *J* = 13.0, 8.3, 7.8 Hz, 1 H, CH₂CH₂NH₂)

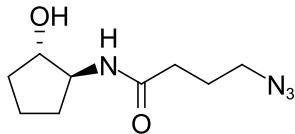
¹³C NMR (101 MHz, MeOD) δ / ppm = 80.7 (CHOH), 60.8 (CH₂NH₂), 33.2 (CH₂CHOH), 32.1 (CH₂CH₂NH₂), 21.2 (CH₂CH₂CHOH)

HRMS (ESI⁺) *m/z* / Da = 102.0917, [M+H]⁺ found, [C₅H₁₂NO]⁺ requires 102.0913

$[\alpha]_D^{20}$ / °10⁻¹cm²g⁻¹ = -30.9, lit. = -32.9 (*c* / g(100 ml)⁻¹ = 1.5, EtOH)

The data are consistent with the literature.^{168,180}

5.51 4-Azido-*N*-((1*S*,2*S*)-2-hydroxycyclopentyl)butanamide 133



4-Chloro-*N*-((1*S*,2*S*)-2-hydroxycyclopentyl)butanamide **154** (35.0 mg, 0.170 mmol, 1 eq.) and Na₃N (22.1 mg, 0.340 mmol, 2 eq.) were stirred in acetonitrile (2 ml) at 50 °C for 24 h. The reaction mixture was then partitioned between water (20 ml) and 10 % *i*-PrOH/CHCl₃ (5 ml). The aqueous layer was extracted again with 10 % *i*-PrOH/CHCl₃ (2×5 ml) and the combined organic fractions were dried with MgSO₄ and evaporated under reduced pressure. **133** was obtained as white needles (16.2 mg, 0.0764 mmol, 45.0 %).

TLC R_f = 0.35 (EtOAc)

IR (neat) ν_{max} / cm⁻¹ = 3286.7 (N-H and O-H), 2957.6 (C-H), 2930.6 (C-H), 2860.7 (C-H), 2094.7 (azide), 1642.2 (amide C=O)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 5.82 (br s, 1 H, NH), 4.45 (br. s., 1 H, OH), 3.96 (q, J = 6.6 Hz, 1 H, CHOH), 3.83 (tdd, J = 8.5, 6.0, 4.6 Hz, 1 H, CHNH), 3.37 (t, J = 6.4 Hz, 2 H, CH₂N₃), 2.31 (t, J = 7.2 Hz, 2 H, CH₂C=O), 2.09 - 2.19 (m, 1 H, CHHCHNH), 1.99 - 2.06 (m, 1 H, CHHCHOH), 1.90 - 1.97 (m, 2 H, CH₂CH₂N₃), 1.60 - 1.85 (m, 3 H, CH₂CHHCHOH), 1.42 (dq, J = 12.8, 8.3 Hz, 1 H, CHHCHNH)

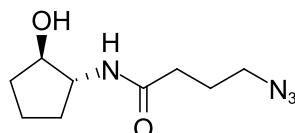
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 173.8 (C=O), 79.7 (CHOH), 61.0 (CHNH), 50.7 (CH₂N₃), 32.8 (CH₂C=O), 32.6 (CH₂CHOH), 30.5 (CH₂CHNH), 24.7 (CH₂CH₂N₃), 21.3 (CH₂CH₂CHOH)

HRMS (ESI⁺) m/z / Da = 235.1178, [M+Na]⁺ found, [C₉H₁₆N₄NaO₂]⁺ requires 235.1171

$[\alpha]_D^{20}$ / ${}^{\circ}10^{-1}\text{cm}^2\text{g}^{-1}$ = 10.0 (c / g(100 ml)⁻¹ = 0.01, MeOH)

The compound has not been reported previously.

5.52 4-Azido-*N*-((1*R*,2*R*)-2-hydroxycyclopentyl)butanamide 134



4-Chloro-*N*-((1*R*,2*R*)-2-hydroxycyclopentyl)butanamide **155** (200 mg, 0.972 mmol, 1 eq.) and NaN₃ (126 mg, 1.94 mmol, 2 eq.) were stirred in acetonitrile (4 ml) at 50 °C for 16 h. The solvent was then evaporated under reduced pressure and the residue was partitioned between water (20 ml) and 10 % *i*-PrOH/CHCl₃ (20 ml). The aqueous layer was extracted again with 10 % *i*-PrOH/CHCl₃ (3×20 ml) and the combined organic fractions were dried with MgSO₄ and evaporated under reduced pressure. **134** was obtained as white needles (181 mg, 0.852 mmol, 87.6 %).

TLC R_f = 0.35 (EtOAc)

mp T / °C = 56.0-59.5 (*i*-PrOH, CHCl₃)

IR (neat) ν_{max} / cm⁻¹ = 3279.9 (N-H and O-H), 2965.6 (C-H), 2875.4 (C-H), 2094.6 (azide), 1636.8 (amide C=O)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 6.72 (d, J = 4.4 Hz, 1 H, NH), 4.82 (br. s., 1 H, OH), 3.88 (q, J = 6.6 Hz, 1 H, CHOH), 3.75 (tdd, J = 8.4, 6.6, 4.4 Hz, 1 H, CHNH), 3.28 (t, J = 6.6 Hz, 2 H, CH₂N₃), 2.23 (t, J = 7.3 Hz, 2 H, CH₂C=O), 2.04 (dtd, J = 13.0, 8.0, 4.9 Hz, 1 H, CHHCHNH), 1.92 (dtd, J = 13.0, 7.6, 5.8 Hz, 1 H, CHHCHOH), 1.84 (quin, J = 7.0 Hz, 2 H, CH₂CH₂N₃), 1.59 - 1.77 (m, 2 H, CH₂CH₂CHOH), 1.54 (ddt, J = 12.7, 9.0, 6.7 Hz, 1 H, CHHCHOH), 1.39 (dq, J = 12.9, 8.4 Hz, 1 H, CHHCHNH)

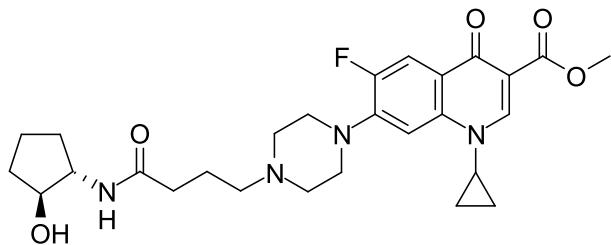
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 173.8 (C=O), 78.8 (CHOH), 59.9 (CHNH), 50.5 (CH₂N₃), 32.5 (CH₂C=O), 32.0 (CH₂CHOH), 29.5 (CH₂CHNH), 24.6 (CH₂CH₂N₃), 20.7 (CH₂CH₂CHOH)

HRMS (ESI⁺) m/z / Da = 235.1174, [M+Na]⁺ found, [C₉H₁₆N₄NaO₂]⁺ requires 235.1171

$[\alpha]_D^{20}$ / ${}^{\circ}10^{-1}\text{cm}^2\text{g}^{-1}$ = -10.2 (c / g(100 ml)⁻¹ = 0.5, MeOH)

The compound has not been reported previously.

5.53 Methyl 1-cyclopropyl-6-fluoro-7-(4-((1*S*,2*S*)-2-hydroxycyclopentyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 135



4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid trifluoroacetate **152** (52.1 mg, 95.5 μ mol, 1 eq.), (1*S*,2*S*)-2-aminocyclopentan-1-ol **129** (19.5 mg, 193 μ mol, 2 eq.), 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide hydrochloride (29.7 mg, 155 μ mol, 1.6 eq.), 1-hydroxybenzotriazole (25.8 mg, 191 μ mol, 2 eq.) and DIPEA (33.3 μ l, 24.7 mg, 191 μ mol, 2 eq.) were dissolved in DMF (2 ml) and stirred at r.t. for 16 h. The solvent was removed using a stream of N_2 and the residue was purified by preparative HPLC (5-50 % acetonitrile/water over 15 min). The combined pure fractions were evaporated under reduced pressure and then partitioned between $NaHCO_3$ (aq., sat., 5 ml) and CH_2Cl_2 (5 ml). The organic layer was removed and the aqueous layer was extracted twice more with CH_2Cl_2 (2 \times 5 ml). The combined organic fractions were dried with $MgSO_4$ and evaporated under reduced pressure. **135** was obtained as a white amorphous solid (26.9 mg, 52.3 μ mol, 54.7 %).

TLC R_f = 0.38 (30 % MeOH/ CH_2Cl_2)

IR (neat) ν_{max} / cm^{-1} = 2937.7 (C-H), 1721.4 (ester C=O), 1620.5 (amide C=O and quinolone C=O)

1H NMR (500 MHz, DMSO d₆) δ / ppm = 8.44 (s, 1 H, *ortho* to C(=O)OCH₃), 7.75 (d, J = 13.5 Hz, 1 H, *ortho* to F), 7.69 (d, J = 6.9 Hz, 1 H, CHNH), 7.43 (d, J = 7.6 Hz, 1 H, *meta* to F), 4.73 (br s, 1 H, CHO_H), 3.77 - 3.81 (m, 1 H, CHO_H), 3.74 - 3.77 (m, 1 H, CHNH), 3.73 (s, 3 H, CH₃), 3.65 (tt, J = 6.9, 4.0 Hz, 1 H, NCH(CH₂)₂), 3.24 (br. t, J = 4.2 Hz, 4 H, CH₂N(CH₂CH₂)CH₂CH₂), 2.55 (br t, J = 5.0 Hz, 4 H, CH₂N(CH₂)CH₂), 2.32 (t, J = 7.2 Hz, 2 H, CH₂N(CH₂)CH₂), 2.10 (t, J = 7.4 Hz, 2 H, CH₂CH₂CH₂N(CH₂)CH₂), 1.92 (dddd, J = 13.0, 8.7, 7.3, 6.0 Hz, 1 H, CHHCHNH), 1.77 (ddt, J = 12.6, 8.9, 6.3 Hz, 1 H, CHHCHOH), 1.68 (quin, J = 7.4 Hz, 2 H, CH₂CH₂N(CH₂)CH₂), 1.53 - 1.64 (m, 2 H, CH₂CH₂CHOH), 1.42 (ddt, J = 12.9, 8.4, 5.2 Hz, 1 H, CHHCHOH), 1.31 (ddt, J = 13.0, 8.6, 6.4 Hz, 1 H, CHHCHNH), 1.22 - 1.28 (m, 2 H, NCH(CHH)₂), 1.06 - 1.12 (m, 2 H, NCH(CHH)₂)

^{13}C NMR (126 MHz, DMSO d₆) δ / ppm = 171.9 (NHC(=O)CH₂), 171.5 (C(=O)CC(=O)OCH₃), 165.0 (C(=O)OCH₃), 152.6 (d, J = 247.4 Hz, *ipso* to F), 148.2 (C=CC(=O)OCH₃), 143.9 (d, J = 10.3 Hz, *ipso* to piperazine), 138.1 (*para* to F), 121.7 (d, J = 6.4 Hz, *para* to piperazine), 111.5 (d, J = 23.0 Hz, *ortho* to C=O and *ortho* to F), 109.0 (CC(=O)OCH₃), 106.2 (*meta* to C=O and *meta* to F), 76.2 (CHO_H), 57.6 (CHNH), 57.2 (CH₂CH₂CH₂N), 52.4 (CH₂CH₂CH₂N(CH₂)CH₂), 51.3 (CH₃), 49.6 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 49.6 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 34.7 (NCH(CH₂)₂), 33.2 (C(=O)CH₂), 32.2 (CH₂CHOH), 29.5 (CH₂CH NH), 22.5 (C(=O)CH₂CH₂), 20.6 (CH₂CH₂CHOH), 7.5 (NCH(CH₂)₂)

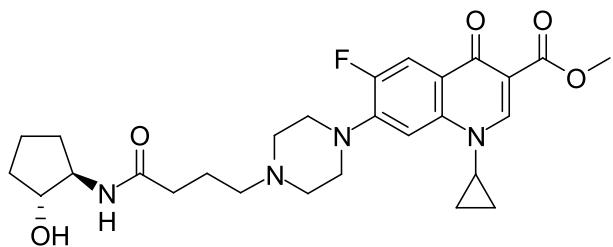
^{19}F NMR (376.45 MHz, MeOD) δ / ppm = -125.5

HRMS (ESI⁺) m/z / Da = 515.2667, [M+H]⁺ found, [C₂₇H₃₆FN₄O₅]⁺ requires 515.2670

$[\alpha]_D^{20} / {}^\circ 10^{-1} \text{cm}^2 \text{g}^{-1} = 8.0$ ($c / \text{g(100 ml)}^{-1} = 0.05$, MeOH)

The compound has not been reported previously.

5.54 Methyl 1-cyclopropyl-6-fluoro-7-(4-((1*R*,2*R*)-2-hydroxycyclopentyl)amin o)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 136



4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid trifluoroacetate **152** (200 mg, 0.367 mmol, 1 eq.), (1*R*,2*R*)-2-aminocyclopentan-1-ol **130** (80 mg, 0.791 mmol, 2.1 eq.), 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide hydrochloride (112 mg, 0.584 mmol, 1.6 eq.), 1-hydroxyben zotriazole (96 mg, 0.710 mmol, 1.9 eq.) and DIPEA (192 μ l, 142 mg, 1.10 mmol, 3 eq.) were dissolved in DMF (5 ml) and stirred at r.t. for 16 h. The solvent was removed using a stream of N₂ and the residue was purified by preparative HPLC (5-60 % acetonitrile/water over 12 min). The combined pure fractions were evaporated under reduced pressure and then partitioned between NaHCO₃ (aq., sat., 10 ml) and CH₂Cl₂ (10 ml). The organic layer was removed and the aqueous layer was extracted twice more with CH₂Cl₂ (2×10 ml). The combined organic fractions were dried with MgSO₄ and evaporated under reduced pressure. **136** was obtained as a white amorphous solid (73.0 mg, 0.142 mmol, 38.7 %).

TLC $R_f = 0.43$ (30 % MeOH/EtOAc)

IR (neat) $\nu_{max} / \text{cm}^{-1} = 2972.9$ (C-H), 2901.5 (C-H), 1728.4 (ester C=O), 1656.3 (amide C=O), 1612.9 (quinolone C=O)

¹H NMR (400 MHz, DMSO d₆) $\delta / \text{ppm} = 8.44$ (s, 1 H, *ortho* to C(=O)OCH₃), 7.75 (d, $J = 13.5$ Hz, 1 H, *ortho* to F), 7.70 (d, $J = 7.2$ Hz, 1 H, CHNH), 7.43 (d, $J = 7.5$ Hz, 1 H, *meta* to F), 4.74 (d, $J = 4.0$ Hz, 1 H, CHO_H), 3.78 - 3.82 (m, 1 H, CHO_H), 3.74 - 3.78 (m, 1 H, CHNH), 3.74 (s, 3 H, CH₃), 3.65 (tt, $J = 7.2, 3.9$ Hz, 1 H, NCH(CH₂)₂), 3.25 (t, $J = 4.8$ Hz, 4 H, CH₂N(CH₂CH₂)CH₂CH₂), 2.57 (br s, 4 H, CH₂N(CH₂)CH₂), 2.34 (t, $J = 7.4$ Hz, 2 H, CH₂N(CH₂)CH₂), 2.11 (t, $J = 7.4$ Hz, 2 H, CH₂CH₂CH₂N(CH₂)CH₂), 1.92 (dddd, $J = 13.0, 8.7, 7.3, 6.0$ Hz, 1 H, CHHCHNH), 1.78 (dddd, $J = 12.6, 8.9, 6.3, 6.3$ Hz, 1 H, CHHCHOH), 1.69 (quin, $J = 7.3$ Hz, 2 H, CH₂CH₂N(CH₂)CH₂), 1.54 - 1.65 (m, 2 H, CH₂CH₂CHOH), 1.42 (ddt, $J = 13.1, 8.2, 5.3$ Hz, 1 H, CHHCHOH), 1.32 (dddd, $J = 13.4, 8.5, 6.8, 5.8$ Hz, 1 H, CHHCHNH), 1.21 - 1.29 (m, 2 H, NCH(CHH)₂), 1.07 - 1.13 (m, 2 H, NCH(CHH)₂)

¹³C NMR (101 MHz, DMSO d₆) $\delta / \text{ppm} = 171.9$ (CH₂C(=O)NH), 171.6 (C(=O)CC(=O)OCH₃), 165.0 (C(=O)OCH₃), 152.6 (d, $J = 246.5$ Hz, *ipso* to F), 148.3 (C=CC(=O)OCH₃), 143.9 (d, $J = 10.7$ Hz, *ipso* to piperazine), 138.1 (*para* to F), 121.8 (d, $J = 6.4$ Hz, *para* to piperazine), 111.5 (d, $J = 22.4$ Hz, *ortho* to C=O and *ortho* to F), 109.0 (CC(=O)OCH₃), 106.2 (*meta* to C=O and *meta* to F), 76.3 (CHOH), 57.6 (CHNH),

57.2 (CH₂CH₂CH₂N), 52.4 (CH₂CH₂CH₂N(CH₂)CH₂), 51.3 (CH₃), 49.6 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 34.8 (NCH(CH₂)₂), 33.3 (C(=O)CH₂), 32.2 (CH₂CHOH), 29.5 (CH₂CHNH), 22.5 (C(=O)CH₂CH₂), 20.6 (CH₂CH₂CHOH), 7.6 (NCH(CH₂)₂)

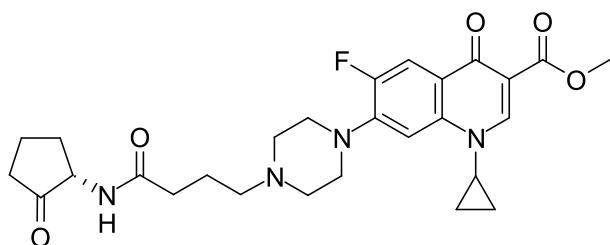
¹⁹F NMR (376.45 MHz, DMSO d₆) δ / ppm = -124.3 (ciprofloxacin F)

HRMS (ESI⁺) *m/z* / Da = 515.2661, [M+H]⁺ found, [C₂₇H₃₆FN₄O₅]⁺ requires 515.2670

[α]_D²⁰ / °10⁻¹cm²g⁻¹ = -6.0 (c / g(100 ml)⁻¹ = 0.05, MeOH)

The compound has not been reported previously.

5.55 Methyl (S)-1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxocyclopentyl)amino)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 137



Methyl 1-cyclopropyl-6-fluoro-7-(4-((1*S*,2*S*)-2-hydroxycyclopentyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate **135** (20.0 mg, 38.9 μmol, 1 eq.) and Dess-Martin periodinane (32.8 mg, 77.4 μmol, 2 eq.) were stirred in CH₂Cl₂ (3 ml) for 6 h. The solvent was removed under reduced pressure and the residue was purified by preparative HPLC (5-50 % acetonitrile/water over 10 min). The combined pure fractions were evaporated under reduced pressure, then NaHCO₃ (aq., sat., 30 ml) and 10 % *i*-PrOH/CHCl₃ (30 ml) were added. The organic layer was removed and dried with MgSO₄, then evaporated under reduced pressure. **137** was obtained as a white amorphous solid (11.3 mg, 22.0 μmol, 56.7 %).

¹H NMR (500 MHz, DMSO d₆) δ / ppm = 8.46 (s, 1 H, *ortho* to C(=O)OCH₃), 7.78 (d, *J* = 13.5 Hz, 1 H, *ortho* to F), 7.45 (d, *J* = 7.4 Hz, 1 H, *meta* to F), 4.02 (dt, *J* = 11.1, 8.2 Hz, 1 H, CHNH), 3.73 (s, 3 H, CH₃), 3.65 (tt, *J* = 6.9, 3.9 Hz, 1 H, NCH(CH₂)₂), 3.40 (s, 10 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.05 - 2.29 (m, 5 H, NHC(=O)CH₂, CH₂C(=O)CHNH and CH₂CH₂CHNH), 1.89 - 1.96 (m, 1 H, CH₂CH₂CHNH), 1.69 - 1.80 (m, 3 H, CH₂CH₂CHNH, CH₂CH₂CHNH and NHC(=O)CH₂CH₂), 1.24 - 1.29 (m, 2 H, NCH(CH₂)₂), 1.07 - 1.12 (m, 2 H, NCH(CH₂)₂)

¹³C NMR (126 MHz, DMSO d₆) δ / ppm = 215.2 (C(=O)CHNH), 171.7 (NHC(=O)CH₂), 171.7 (C(=O)CC(=O)OCH₃), 165.1 (C(=O)OCH₃), 152.6 (d, *J* = 246.6 Hz, *ipso* to F), 148.4 (C=CC(=O)OCH₃), 138.1 (*para* to F), 109.1 (CC(=O)OCH₃), 56.3 (CHNH), 51.4 (CH₃), 35.6 (CH₂C(=O)CHNH), 34.8 (NCH(CH₂)₂), 28.8 (CH₂CHNH), 18.1 (CH₂CH₂CHNH), 7.6 (NCH(CH₂)₂)

¹⁹F NMR (376.45 MHz, MeOD) δ / ppm = -124.3

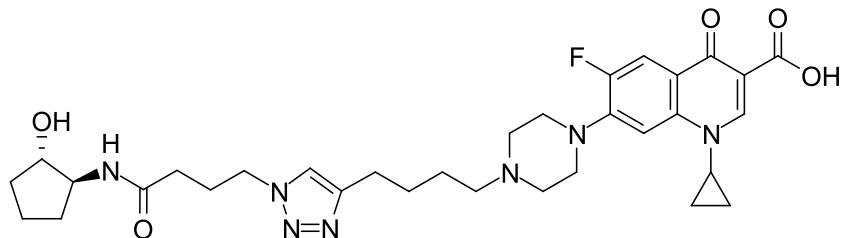
HRMS (ESI⁺) *m/z* / Da = 513.2495, [M+H]⁺ found, [C₂₇H₃₄FN₄O₅]⁺ requires 513.2513

remove
unless
very
active
as not
fully
characterised

$$[\alpha]_D^{20} / \text{cm}^2 \text{g}^{-1} = 6.7 \ (c / \text{g(100 ml)}^{-1} = 0.075, \text{ MeOH})$$

The compound has not been reported previously.

5.56 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-((1*S*,2*S*)-2-hydroxycyclopentyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 138



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **76** (82.0 mg, 199 μmol , 4 eq.) and 4-azido-*N*-((1*S*,2*S*)-2-hydroxycyclopentyl)butanamide **133** (11.0 mg, 51.8 μmol , 1 eq.) were dissolved in 10 % water/*t*-BuOH (3 ml), and the mixture was degassed by bubbling N_2 through it. A solution of CuSO_4 and THPTA (156 μl , 15.6 μmol , 0.3 eq. 100 mM, aq.) was added, followed by a solution of sodium ascorbate (312 μl , 31.2 μmol , 0.6 eq., 100 mM, aq.). The mixture was stirred at room temperature under argon for 3 d. Water (10 ml) and 10 % *i*-PrOH/CHCl₃ (10 ml) were added, then the organic layer was separated and dried with MgSO₄ and evaporated under reduced pressure. The residue was purified by preparative HPLC (5-95 % acetonitrile/water over 20 min). The combined pure fractions were evaporated under reduced pressure and then partitioned between NaHCO₃ (aq., sat., 10 ml) and 10 % *i*-PrOH/CHCl₃ (10 ml). The organic layer was dried with MgSO₄ and evaporated under reduced pressure. **138** was obtained as a white amorphous solid (7.2 mg, 11.5 μmol , 22.2 %).

IR (neat) $\nu_{max} / \text{cm}^{-1} = 2954.9$ (C-H), 2917.9 (C-H), 2850.2 (C-H), 1722.1 (carboxylic acid C=O), 1647.3 (amide C=O), 1626.7 (quinolone C=O) 1611.9 (triazole)

¹H NMR (400 MHz, DMSO d₆) $\delta / \text{ppm} = 15.22$ (br s, 1 H, C(=O)OH), 8.67 (s, 1 H, *ortho* to C(=O)OH), 7.91 (d, $J = 13.3$ Hz, 1 H, *ortho* to F), 7.84 (s, 1 H, CH=CCH₂), 7.74 (d, $J = 6.7$ Hz, 1 H, CHNH), 7.56 (d, $J = 7.4$ Hz, 1 H, *meta* to F), 4.71 (d, $J = 3.7$ Hz, 1 H, CHOH), 4.29 (t, $J = 6.6$ Hz, 2 H, CH₂NCH=C), 3.82 (tt, $J = 6.5, 4.3$ Hz, 1 H, NCH(CH₂)₂), 3.69 - 3.79 (m, 2 H, CH₂OH and CHNH), 3.30 - 3.34 (m, 6 H, CH=CCH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.64 (t, $J = 7.4$ Hz, 2 H, CH=CCH₂), 1.95 - 2.08 (m, 4 H, C(=O)CH₂CH₂), 1.89 (dddd, $J = 12.8, 8.9, 7.4, 5.8$ Hz, 1 H, CH₂CH₂CHNH), 1.75 (ddt, $J = 12.7, 9.0, 6.2$ Hz, 1 H, CH₂CH₂CHOH), 1.48 - 1.68 (m, 6 H, CH=CCH₂CH₂CH₂ and CH₂CH₂CHOH), 1.40 (ddt, $J = 13.0, 8.3, 5.3$ Hz, 1 H, CH₂CH₂CHOH), 1.28 - 1.35 (m, 2 H, NCH(CH₂)₂), 1.24 - 1.31 (m, 1 H, CH₂CH₂CHNH), 1.15 - 1.21 (m, 2 H, NCH(CH₂)₂)

¹³C NMR (101 MHz, DMSO d₆) $\delta / \text{ppm} = 176.4$ (C(=O)CC(=O)OH), 170.9 (NHC(=O)CH₂), 166.0 (C(=O)OH), 153.0 (d, $J = 249.6$ Hz, *ipso* to F), 148.1 (C=CC(=O)OH), 146.7 (CH=CCH₂), 145.2 (d, $J = 8.3$ Hz, *ipso* to piperazine), 139.2 (*para* to F), 121.8 (NCH=CCH₂), 118.7 (*para* to piperazine), 111.0 (d, $J = 23.2$ Hz, *ortho* to C=O and *ortho* to F), 106.7 (CC(=O)OH), 106.5 (*meta* to C=O and *meta* to F), 76.2 (CH₂OH), 57.5 (CHNH), 57.4 (br s, CH=CCH₂CH₂CH₂N(CH₂CH₂)), 52.3 (br s, CH=CCH₂CH₂CH₂CH₂N(CH₂CH₂)), 49.3 (br s, CH=CCH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 48.8 (CH₂NCH=CCH₂), 35.9 (NCH(CH₂)₂), 32.2 (CH₂CHOH),

32.0 (C(=O)CH₂), 29.4 (CH₂CHNH), 26.7 (CH=CCH₂CH₂), 26.0 (C(=O)CH₂CH₂), 25.5 (CH=CCH₂CH₂CH₂), 24.9 (CH=CCH₂CH₂), 20.5 (CH₂CH₂CHOH), 7.6 (NCH(CH₂)₂)

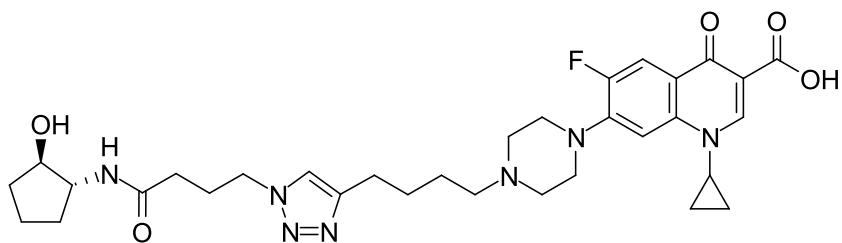
¹⁹F NMR (376.45 MHz, MeOD) δ / ppm = -121.5

HRMS (ESI⁺) *m/z* / Da = 624.3298, [M+H]⁺ found, [C₃₂H₄₃FN₇O₅]⁺ requires 624.3310

$[\alpha]_D^{20}$ / °10⁻¹cm²g⁻¹ = -25.0 (c / g(100 ml)⁻¹ = 0.08, MeOH)

The compound has not been reported previously.

5.57 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-(((1*R*,2*R*)-2-hydroxycyclopentyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 139



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **76** (42.9 mg, 104 μ mol, 1 eq.) and 4-azido-*N*-((1*R*,2*R*)-2-hydroxycyclopentyl)butanamide **134** (22.0 mg, 104 μ mol, 1 eq.) were dissolved in 10 % water/*t*-BuOH (3 ml), and the mixture was degassed by bubbling N₂ through it. A solution of CuSO₄ and THPTA (104 μ l, 10.4 μ mol, 0.1 eq. 100 mM, aq.) was added, followed by a solution of sodium ascorbate (208 μ l, 20.8 μ mol, 0.2 eq., 100 mM, aq.). The mixture was stirred at room temperature under argon for 16 h. Water (30 ml) and CH₂Cl₂ (30 ml) were added, the organic layer was separated and the aqueous layer was extracted again with CH₂Cl₂ (4×30 ml). The combined organic layers were dried with MgSO₄ and evaporated under reduced pressure. The residue was purified by preparative HPLC (5-95 % acetonitrile/water over 20 min). The combined pure fractions were evaporated under reduced pressure and then partitioned between NaHCO₃ (aq., sat., 10 ml) and 10 % *i*-PrOH/CHCl₃ (10 ml). The organic layer was dried with MgSO₄ and evaporated under reduced pressure. **139** was obtained as a white amorphous solid (17.6 mg, 28.2 μ mol, 27.1 %).

IR (neat) ν_{max} / cm⁻¹ = 2967.0 (C-H), 2902.2 (C-H), 1721.4 (carboxylic acid C=O), 1646.7 (amide C=O), 1627.0 (quinolone C=O), 1613.0 (triazole)

¹H NMR (700 MHz, DMSO d₆) δ / ppm = 8.64 (s, 1 H, *ortho* to C(=O)OH), 7.87 (d, *J* = 13.3 Hz, 1 H, *ortho* to F), 7.84 (s, 1 H, CH=CCH₂), 7.75 (d, *J* = 7.1 Hz, 1 H, CHNH), 7.54 (d, *J* = 7.5 Hz, 1 H, *meta* to F), 4.73 (d, *J* = 3.8 Hz, 1 H, CHOH), 4.29 (t, *J* = 6.9 Hz, 2 H, CH₂NCH=C), 3.78 - 3.83 (m, 1 H, NCH(CH₂)₂), 3.75 - 3.78 (m, 1 H, CHOH), 3.71 - 3.75 (m, 1 H, CHNH), 3.31 (br t, *J* = 4.3 Hz, 4 H, CH₂N(CH₂CH₂)CH₂CH₂), 2.63 (t, *J* = 7.5 Hz, 2 H, CH=CCH₂), 2.56 (br t, *J* = 4.2 Hz, 4 H, CH₂N(CH₂)CH₂), 2.37 (t, *J* = 7.3 Hz, 2 H, CH₂N(CH₂)CH₂), 2.03 - 2.06 (m, 2 H, C(=O)CH₂), 1.97 - 2.02 (m, 2 H, C(=O)CH₂CH₂), 1.89 (dd, *J* = 13.1, 8.9, 7.4, 5.7 Hz, 1 H, CHHCHNH), 1.75 (ddt, *J* = 13.0, 8.9, 6.4, 6.4 Hz, 1 H, CHHCHOH), 1.61 - 1.66 (m, 2 H, CH=CCH₂CH₂), 1.57 - 1.61 (m, 1 H, CHHCH₂CHOH), 1.54 - 1.57 (m, 1 H, CHHCH₂CHOH), 1.49 -

1.53 (m, 2 H, CH=CCH₂CH₂CH₂), 1.40 (ddt, *J* = 13.0, 8.4, 5.3, 5.3 Hz, 1 H, CHHCHOH), 1.29 - 1.32 (m, 2 H, NCH(CHH)₂), 1.25 - 1.29 (m, 1 H, CHHCHNH), 1.13 - 1.20 (m, 2 H, NCH(CHH)₂)

¹³C NMR (175 MHz, DMSO d₆) δ / ppm = 176.3 (C(=O)CC(=O)OH), 170.9 (NHC(=O)CH₂), 166.1 (C(=O)OH), 153.0 (d, *J* = 251.4 Hz, *ipso* to F), 147.9 (C=CC(=O)OH), 146.9 (CH=CCH₂), 145.2 (d, *J* = 8.7 Hz, *ipso* to piperazine), 139.2 (*para* to F), 121.7 (NCH=CCH₂), 118.7 (d, *J* = 5.8 Hz, *para* to piperazine), 111.0 (d, *J* = 23.3 Hz, *ortho* to C=O and *ortho* to F), 106.3 (*meta* to C=O and *meta* to F and CC(=O)OH), 76.2 (CHOH), 57.6 (CHNH), 57.4 (CH=CCH₂CH₂CH₂CH₂N), 52.5 (CH=CCH₂CH₂CH₂CH₂N(CH₂)CH₂), 49.5 (d, *J* = 4.4 Hz, CH=CCH₂CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 48.8 (CH₂NCH=CCH₂), 35.8 (NCH(CH₂)₂), 32.2 (CH₂CHOH), 32.0 (C(=O)CH₂), 29.5 (CH₂CHNH), 26.9 (CH=CCH₂CH₂), 26.0 (C(=O)CH₂CH₂), 25.8 (CH=CCH₂CH₂CH₂), 25.0 (CH=CCH₂), 20.5 (CH₂CH₂CHOH), 7.6 (NCH(CH₂)₂)

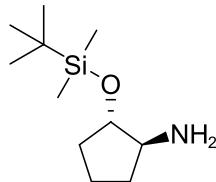
¹⁹F NMR (376.45 MHz, MeOD) δ / ppm = -122.1 (s, ciprofloxacin F)

HRMS (ESI⁺) *m/z* / Da = 624.3314, [M+H]⁺ found, [C₃₂H₄₃FN₇O₅]⁺ requires 624.3310

$[\alpha]_D^{20} / {}^\circ 10^{-1} \text{cm}^2 \text{g}^{-1} = -3.6$ (*c* / g(100 ml)⁻¹ = 0.0833, MeOH)

The compound has not been reported previously.

5.58 (1*S*,2*S*)-2-((*tert*-Butyldimethylsilyl)oxy)cyclopentan-1-amine 140



(1*S*,2*S*)-2-Aminocyclopentan-1-ol **129** (0.480 g, 4.75 mmol) was stirred in dry CH₂Cl₂ (20 ml) under N₂ at 0 °C. TEA (3.14 ml, 2.28 g, 22.5 mmol, 5 eq.) was added dropwise, followed by TBDMsOTf (3 ml, 3.45 g, 13.1 mmol, 3 eq.) dropwise. The reaction was allowed to reach r.t. and stirred for 1 h. The reaction was washed with water (20 ml) and the organic phase dried with Na₂SO₄, concentrated under reduced pressure and purified by column chromatography (SiO₂, 4 % MeOH/CH₂Cl₂). **140** was obtained as a yellow oil (1.00 g, 4.64 mmol, 97.7 %).

TLC *R_f* = 0.23 (10 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 2953.6 (C-H), 2931.1 (C-H), 2888.4 (C-H), 2858.8 (C-H), 1625.2 (N-H bend)

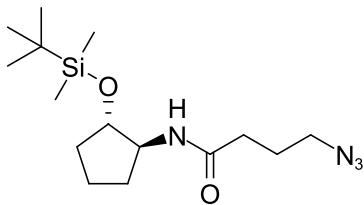
¹H NMR (400 MHz, CDCl₃) δ / ppm = 4.13 (q, *J* = 5.8 Hz, 1 H, CHOSi), 3.31 (td, *J* = 7.1, 5.2 Hz, 1 H, CHNH₂), 2.09 - 2.19 (m, 1 H, CHHCHNH₂), 1.97 (ddq, *J* = 8.8, 7.0, 6.0 Hz, 1 H, CHHCHOSi), 1.74 - 1.86 (m, 2 H, CH₂CH₂CHOSi), 1.64 - 1.74 (m, 1 H, CHHCHOSi), 1.58 (ddt, *J* = 13.2, 9.1, 6.0 Hz, 1 H, CHHCHNH₂), 0.88 (s, 9 H, C(CH₃)₃), 0.09 (s, 3 H, SiCH₃), 0.07 (s, 3 H, SiCH₃)

¹³C NMR (101 MHz, CDCl₃) δ / ppm = 76.3 (CHOSi), 59.7 (CHNH), 32.2 (CH₂CHOSi), 26.8 (CH₂CHNH₂), 25.6 (C(CH₃)₃), 19.7 (CH₂CH₂CHOSi), 17.7 (C(CH₃)₃), -4.8 (SiCH₃), -5.2 (SiCH₃)

HRMS (ESI⁺) m/z / Da = 216.1785, [M+H]⁺ found, [C₁₁H₂₆NOSi]⁺ requires 216.1784

$[\alpha]_D^{20} / {}^\circ 10^{-1} \text{cm}^2 \text{g}^{-1} = 40.0$ ($c / \text{g(100 ml)}^{-1} = 0.05$, MeOH) The compound has not been reported previously.

5.59 4-Azido-*N*-(*(1S,2S)*-2-((*tert*-butyldimethylsilyl)oxy)cyclopentyl)butanamide 144



(*1S,2S*)-2-((*tert*-Butyldimethylsilyl)oxy)cyclopentan-1-amine **140** (50 mg, 0.232 mmol, 1 eq.) and NaHCO₃ (22.0 mg, 0.262 mmol, 1.1 eq.) were added to CH₂Cl₂ (3 ml) and water (3 ml) at 0 °C, and 4-bromobutyryl chloride (25.3 ml, 40.5 mg, 0.219 mmol, 0.95 eq.) was added dropwise. The mixture was stirred for 3 h at 0 °C. The aqueous layer was removed and NaN₃ (100 mg, 1.54 mmol, 6.6 eq.) and DMF (3 ml) were added. The mixture was then stirred at 40 °C for 6 h. The solvents were then evaporated using a N₂ stream and the residue was purified by column chromatography (SiO₂, 0.5 % MeOH/CH₂Cl₂). The combined pure fractions were dried with MgSO₄ and evaporated under reduced pressure. **144** was obtained as a clear liquid (71 mg, 0.217 mmol, 99.2 %).

TLC $R_f = 0.84$ (1 % MeOH/CH₂Cl₂)

IR (neat) $\nu_{max} / \text{cm}^{-1} = 3287.9$ (N-H), 2953.4 (C-H), 2933.2 (C-H), 2882.7 (C-H), 2857.1 (C-H), 2094.9 (azide), 1639.4 (amide C=O)

¹H NMR (400 MHz, CDCl₃) $\delta / \text{ppm} = 5.35$ (d, $J = 5.1$ Hz, 1 H, NH), 3.97 - 4.01 (m, 1 H, CHOSi), 3.93 - 3.98 (m, 1 H, CHNH), 3.35 (t, $J = 6.6$ Hz, 2 H, CH₂N₃), 2.24 (t, $J = 7.0$ Hz, 2 H, CH₂C=O), 2.09 - 2.19 (m, 1 H, CHHCHNH), 1.89 - 1.97 (quin, $J = 6.8$ Hz, 2 H, CH₂CH₂N₃), 1.74 - 1.84 (m, 2 H, CHHCHOSi and CHHCH₂CHOSi), 1.60 - 1.70 (m, 1 H, CHHCH₂CHOSi), 1.51 - 1.61 (m, 1 H, CHHCHOSi), 1.31 - 1.39 (m, 1 H, CHHCHNH), 0.87 (s, 9 H, C(CH₃)₃), 0.08 (s, 3 H, SiCH₃), 0.06 (s, 3 H, SiCH₃)

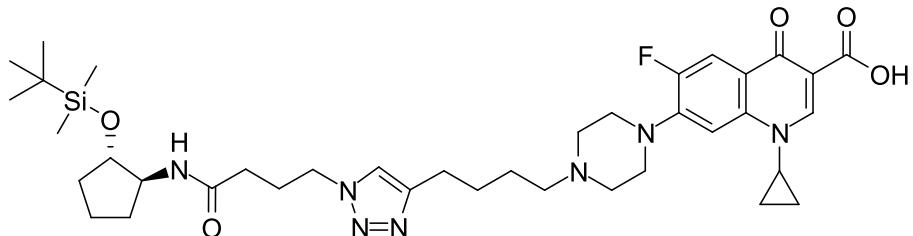
¹³C NMR (101 MHz, CDCl₃) $\delta / \text{ppm} = 171.17$ (C=O), 77.80 (CHOSi), 58.36 (CHNH), 50.77 (CH₂N₃), 33.29 (CH₂C=O), 32.57 (CH₂CHOSi), 29.36 (CH₂CHNH), 25.72 (C(CH₃)₃), 24.77 (CH₂CH₂N₃), 20.40 (CH₂CH₂CHO Si), 17.95 (C(CH₃)₃), -4.75 (SiCH₃)

HRMS (ESI⁺) m/z / Da = 327.2221, [M+H]⁺ found, [C₁₅H₃₁N₄O₂Si]⁺ requires 327.2216

$[\alpha]_D^{20} / {}^\circ 10^{-1} \text{cm}^2 \text{g}^{-1} = 12.4$ ($c / \text{g(100 ml)}^{-1} = 0.5$, MeOH)

The compound has not been reported previously.

5.60 7-(4-(1-(4-((1*S*,2*S*)-2-((*tert*-butyldimethylsilyl)oxy)cyclopentyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **148**



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **76** (42.9 mg, 104 μ mol, 1 eq.) and 4-azido-*N*-((1*S*,2*S*)-2-((*tert*-butyldimethylsilyl)oxy)cyclopentyl)butanamide **144** (33.9 mg, 104 μ mol, 1 eq.) were dissolved in 10 % water/*t*-BuOH (3 ml), and the mixture was degassed by bubbling N₂ through it. A solution of CuSO₄ and THPTA (104 μ l, 10.4 μ mol, 0.1 eq. 100 mM, aq.) was added, followed by a solution of sodium ascorbate (208 μ l, 20.8 μ mol, 0.2 eq., 100 mM, aq.). The mixture was stirred at room temperature under argon for 16 h, then solvent was removed under reduced pressure. The residue was partitioned between water (10 ml) and CH₂Cl₂ (10 ml), the organic layer was separated and the aqueous layer was extracted again with CH₂Cl₂ (10 ml). The combined organic layers were dried with MgSO₄ and evaporated under reduced pressure. **148** was obtained as a clear amorphous solid (67.1 mg, 90.9 μ mol, 87.4 %).

IR (neat) ν_{max} / cm⁻¹ = 2951.3 (C-H), 2929.2 (C-H), 2855.5 (C-H), 1741.0 (carboxylic acid C=O), 1640.3 (amide C=O), 1626.6 (quinolone C=O), 1612.3 (triazole)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 8.67 (s, 1 H, *ortho* to C(=O)OH), 7.87 (d, *J* = 13.1 Hz, 1 H, *ortho* to F), 7.34 (s, 1 H, CH=CCH₂), 7.33 (d, *J* = 8.2 Hz, 1 H, *meta* to F), 5.92 (t, *J* = 6.6 Hz, 1 H, CHNH), 4.35 (t, *J* = 6.7 Hz, 2 H, CH₂NCH=C), 3.96 - 4.02 (m, 1 H, CHOSi), 3.90 - 3.96 (m, 1 H, CHNH), 3.55 (tt, *J* = 6.7, 4.0 Hz, 1 H, NCH(CH₂)₂), 3.34 (br t, *J* = 5.0 Hz, 4 H, CH₂N(CH₂CH₂)CH₂CH₂), 2.71 (t, *J* = 7.5 Hz, 2 H, CH=CCH₂), 2.66 (br s, 4 H, CH₂N(CH₂)CH₂), 2.46 (t, *J* = 7.3 Hz, 2 H, CH₂N(CH₂)CH₂), 2.03 - 2.22 (m, 5 H, CHHCHNH, C(=O)CH₂ and C(=O)CH₂CH₂), 1.65 - 1.83 (m, 4 H, CHHCHOSi, CHHCH₂CHOSi and NCH=CCH₂CH₂), 1.47 - 1.65 (m, 4 H, CHHCHOSi, CHHCH₂CHOSi and NCH=CCH₂CH₂CH₂), 1.33 - 1.41 (m, 3 H, CHHCHNH and NCH(CHH)₂), 1.14 - 1.20 (m, 2 H, NCH(CHH)₂), 0.82 (s, 9 H, C(CH₃)₃), 0.03 (s, 3 H, SiCH₃), 0.01 (s, 3 H, SiCH₃)

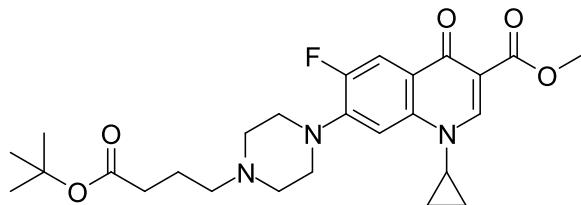
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 176.9 (C(=O)CC(=O)OH), 170.9 (CH₂C(=O)NH), 166.9 (C(=O)OH), 153.5 (d, *J* = 251.4 Hz, *ipso* to F), 147.9 (CH=CCH₂), 147.2 (C=CC(=O)OH), 145.8 (d, *J* = 10.4 Hz, *ipso* to piperazine), 139.0 (*para* to F), 120.9 (NCH=CCH₂), 119.4 (d, *J* = 7.8 Hz, *para* to piperazine), 112.0 (d, *J* = 23.4 Hz, *ortho* to C=O and *ortho* to F), 107.7 (C(=O)OH), 104.7 (d, *J* = 3.5 Hz, *meta* to C=O and *meta* to F), 77.7 (CHOSi), 58.2 (CHNH), 57.9 (CH=CCH₂CH₂CH₂N), 52.6 (CH=CCH₂CH₂CH₂N(CH₂)CH₂), 49.5 (d, *J* = 6.1 Hz, CH=CCH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 48.9 (d, *J* = 3.5 Hz, CH₂NCH=CCH₂), 35.3 (NCH(CH₂)₂), 32.6 (C(=O)CH₂), 32.6 (CH₂CHOSi), 29.3 (CH₂CHNH), 27.2 (CH=CCH₂CH₂), 26.0 - 26.3 (C(=O)CH₂CH₂ and CH=CCH₂CH₂CH₂), 25.6 (C(CH₃)₃), 25.4 (CH=CCH₂), 20.4 (CH₂CH₂CHOSi), 17.8 (C(CH₃)₃), 8.1 (NCH(CH₂)₂), -4.8 (SiCH₃)

HRMS (ESI⁺) *m/z* / Da = 738.4164, [M+H]⁺ found, [C₃₈H₅₇FN₇O₅Si]⁺ requires 738.4169

$$[\alpha]_D^{20} / {}^\circ 10^{-1} \text{cm}^2 \text{g}^{-1} = 4.5 \ (c / \text{g}(100 \text{ ml})^{-1} = 0.2, \text{ MeOH})$$

The compound has not been reported previously.

5.61 Methyl 7-(4-(*tert*-butoxy)-4-oxobutyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylate 151



Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate **108** (200 mg, 0.579 mmol, 1 eq.), *tert*-butyl 4-bromobutanoate **150** (103 μ l, 130 mg, 0.581 mmol, 1 eq.), NaI (86.9 mg, 0.580 mmol, 1 eq.), TEA (316 μ l, 229 mg, 2.27 mmol, 4 eq.) and acetonitrile (10 ml) were stirred in a microwave reactor at 100 $^\circ$ C for 8 h. A second portion of *tert*-butyl 4-bromobutanoate **167** (103 μ l, 130 mg, 0.581 mmol, 1 eq.) was added, and the mixture was stirred in the microwave reactor at 100 $^\circ$ C for a further 8 h. The mixture was then dry-loaded onto SiO₂ and purified by column chromatography (SiO₂, 0-4 % MeOH/CH₂Cl₂). **151** was obtained as a white amorphous solid (141 mg, 0.289 mmol, 49.9 %).

TLC R_f = 0.12 (4 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 2961.6 (C-H), 2830.5 (C-H), 1732.2 (*t*-Bu ester C=O) 1717.2 (ciprofloxacin ester C=O), 1620.6 (quinolone C=O)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 8.39 (s, 1 H, *ortho* to C(=O)OCH₃), 7.82 (d, J = 13.3 Hz, 1 H, *ortho* to F), 7.17 (d, J = 7.2 Hz, 1 H, *meta* to F), 3.83 (s, 3 H, CH₃), 3.40 (tt, J = 7.2, 3.6 Hz, 1 H, NCH(CH₂)₂), 3.22 (t, J = 4.3 Hz, 4 H, CH₂N(CH₂CH₂)CH₂CH₂), 2.63 (t, J = 4.4 Hz, 4 H, CH₂N(CH₂)CH₂), 2.41 (t, J = 7.3 Hz, 2 H, CH₂N(CH₂)CH₂), 2.25 (t, J = 7.4 Hz, 2 H, CH₂CH₂CH₂N(CH₂)CH₂), 1.78 (quin, J = 7.3 Hz, 2 H, CH₂CH₂N(CH₂)CH₂), 1.41 (s, 9 H, C((CH₃)₃), 1.24 (m, 2 H, NCH(CHH)₂), 1.09 (m, 2 H, NCH(CHH)₂)

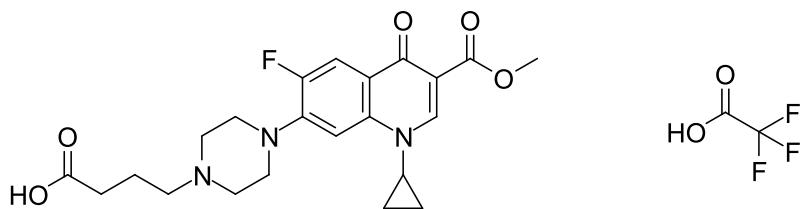
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 172.7 (C(=O)CC(=O)OCH₃), 172.6 (C(=O)OC(CH₃)₃), 165.9 (C(=O)OCH₃), 153.1 (d, J = 249.7 Hz, *ipso* to F), 148.1 (C=CC(=O)OCH₃), 144.3 (d, J = 10.4 Hz, *ipso* to piperazine), 137.7 (*para* to F), 122.5 (d, J = 6.9 Hz, *para* to piperazine) 112.6 (d, J = 22.5 Hz, *ortho* to C=O and *ortho* to F), 109.5 (CC(=O)OCH₃) 104.7 (*meta* to C=O and *meta* to F), 80.0 (C(CH₃)₃), 57.4 (C(=O)CH₂CH₂N(CH₂)), 52.7 (C(=O)CH₂CH₂CH₂N(CH₂CH₂)), 51.7 (CH₃), 49.7 (C(=O)CH₂CH₂CH₂N(CH₂CH₂CH₂)), 49.7 (C(=O)CH₂CH₂CH₂N(CH₂CH₂CH₂)), 34.4 (NCH(CH₂)₂), 33.2 (C(=O)CH₂), 28.0 (C(CH₃)₃), 22.0 (C(=O)CH₂CH₂), 7.9 (NCH(CH₂)₂)

¹⁹F NMR (376.45 MHz, CDCl₃) δ / ppm = -123.5 (s, ciprofloxacin F)

HRMS (ESI⁺) m/z / Da = 488.2562, [M+H]⁺ found, [C₂₆H₃₅FN₃O₅]⁺ requires 488.2561

The compound has not been reported previously.

5.62 4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid trifluoroacetate 152



Methyl 7-(4-(4-(*tert*-butoxy)-4-oxobutyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylate **151** (20 mg, 41.0 μ mol) and TFA (0.2 ml) were stirred in CH_2Cl_2 (1.8 ml) at r.t. for 16 h then evaporated under reduced pressure. **152** was obtained as a white solid (21.4 mg, 39.2 μ mol, 95.6 %).

mp T / $^{\circ}\text{C}$ = 225-231 (CH_2Cl_2 , decomposes)

IR (neat) ν_{max} / cm^{-1} = 1722.7 (ciprofloxacin ester C=O), 1699.0 (alkyl carboxylic acid C=O), 1673.3 (TFA C=O), 1614.6 (quinolone C=O)

$^1\text{H NMR}$ (400 MHz, DMSO d_6) δ / ppm = 8.47 (s, 1 H, *ortho* to C(=O)OH), 7.80 (d, J = 13.2 Hz, 1 H, *ortho* to F), 7.47 (d, J = 7.4 Hz, 1 H, *meta* to F), 3.73 (s, 3 H, CH_3), 3.66 (tt, J = 7.2, 3.7 Hz, 1 H, $\text{NCH}(\text{CH}_2)_2$), 3.30 - 3.54 (br s, 8 H, $\text{CH}_2\text{N}(\text{CH}_2)\text{CH}_2$ and $\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)\text{CH}_2\text{CH}_2$) 3.13 - 3.22 (m, 2 H, $\text{CH}_2\text{N}(\text{CH}_2)\text{CH}_2$), 2.36 (t, J = 7.1 Hz, 2 H, $\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2)\text{CH}_2$), 1.87 - 1.98 (m, 2 H, $\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2)\text{CH}_2$), 1.22 - 1.30 (m, 2 H, $\text{NCH}(\text{CH}_2)_2$), 1.06 - 1.15 (m, 2 H, $\text{NCH}(\text{CH}_2)_2$)

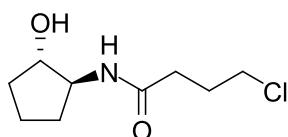
$^{13}\text{C NMR}$ (101 MHz, DMSO d_6) δ / ppm = 173.5 ($\text{CH}_2\text{C}(=\text{O})\text{OH}$), 171.6 ($\text{C}(=\text{O})\text{CC}(=\text{O})\text{OCH}_3$), 164.9 ($\text{C}(=\text{O})\text{OCH}_3$), 158.2 (q, J = 31.5 Hz, $\text{CF}_3\text{C}(=\text{O})\text{OH}$), 152.5 (d, J = 247.6 Hz, *ipso* to F), 148.5 ($\text{C}=\text{CC}(=\text{O})\text{OH}$), 142.3 (d, J = 10.7 Hz, *ipso* to piperazine), 138.0 (*para* to F), 122.6 (d, J = 6.4 Hz, *para* to piperazine), 117.2 (q, J = 299.8 Hz, CF_3), 111.9 (d, J = 22.4 Hz, *ortho* to C=O and *ortho* to F), 109.1 ($\text{C}\text{C}(=\text{O})\text{OCH}_3$), 106.9 (*meta* to C=O and *meta* to F), 55.1 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 51.4 (CH_3), 50.8 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2)\text{CH}_2$), 46.7 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)\text{CH}_2\text{CH}_2$), 34.9 ($\text{NCH}(\text{CH}_2)_2$), 30.6 ($\text{C}(=\text{O})\text{CH}_2$), 19.1 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2$), 7.6 ($\text{NCH}(\text{CH}_2)_2$)

$^{19}\text{F NMR}$ (376.45 MHz, DMSO d_6) δ / ppm = -73.6 (s, CF_3), -124.6 (s, ciprofloxacin F)

HRMS (ESI $^+$) m/z / Da = 432.1921, [M+H] $^+$ found, $[\text{C}_{22}\text{H}_{27}\text{FN}_3\text{O}_5]^+$ requires 432.1935

The compound has not been reported previously.

5.63 4-Chloro-*N*-(*1S,2S*)-2-hydroxycyclopentylbutanamide 154



(1*S,2S*)-2-Aminocyclopentan-1-ol **129** (72.3 mg, 716 μ mol, 1 eq.), TEA (500 μ l, 363 mg, 3.58 mmol, 5 eq.) and CH_2Cl_2 (5 ml) were stirred at 0 °C, and 4-chlorobutyryl chloride **153** (179 μ l, 226 mg, 1.60 mmol, 1.1 eq.) was added dropwise over 5 min. The mixture was stirred at 0 °C for 30 min, then water (10 ml) was added. The organic layer was separated off, and the aqueous layer was extracted with 10 % *i*-PrOH/CHCl₃ (2×10 ml). The combined organic layers were dried with MgSO₄, concentrated under reduced pressure and purified by column chromatography (SiO₂, Et₂O). The combined pure fractions were dried with MgSO₄ and evaporated under reduced pressure. **154** was obtained as a white amorphous solid (35.6 mg, 173 μ mol, 24.2 %).

TLC R_f = 0.35 (EtOAc)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 6.05 (br s, 1 H, NH), 4.55 (br s, 1 H, OH), 3.95 (q, J = 6.6 Hz, 1 H, CHOH), 3.82 (tt, J = 8.4, 5.3 Hz, 1 H, CHNH), 3.60 (t, J = 6.2 Hz, 2 H, CH₂Cl), 2.38 (t, J = 7.0 Hz, 2 H, CH₂C=O), 2.05 - 2.17 (m, 3 H, CHHCHNH and CH₂CH₂Cl), 1.94 - 2.05 (m, 1 H, CHHCHOH), 1.74 - 1.86 (m, 1 H, CHHCH₂CHOH), 1.58 - 1.74 (m, 2 H, CHHCH₂CHOH and CHHCHOH), 1.42 (dq, J = 12.5, 8.4 Hz, 1 H, CHHCHNH)

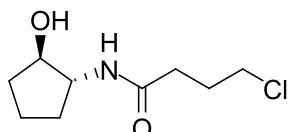
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 173.8 (C=O), 79.4 (CHOH), 60.6 (CHNH), 44.4 (CH₂Cl), 32.8 (CH₂C=O), 32.4 (CH₂CHOH), 30.2 (CH₂CHNH), 28.0 (CH₂CH₂Cl), 21.2 (CH₂CH₂CHOH)

HRMS (ESI⁺) m/z / Da = 206.0939, [M+H]⁺ found, [C₉H₁₇ClNO₂]⁺ requires 206.0948

$[\alpha]_D^{20}$ / °10⁻¹cm²g⁻¹ = 10.0 (*c* / g(100 ml)⁻¹ = 0.05, MeOH)

The compound has not been reported previously.

5.64 4-Chloro-*N*-(*1R,2R*)-2-hydroxycyclopentylbutanamide **155**



(*1R,2R*)-2-Aminocyclopentan-1-ol **130** (500 mg, 4.94 mmol, 1 eq.), TEA (827 μ l, 600 mg, 5.93 mmol, 1.2 eq.) and CH_2Cl_2 (20 ml) were stirred at 0 °C and 4-chlorobutyryl chloride **153** (608 μ l, 766 mg, 5.43 mmol, 1.1 eq.) was added dropwise over 5 min. The mixture was stirred at 0 °C for 30 min, then water (50 ml) was added. The organic layer was separated off, and the aqueous layer was extracted with CH_2Cl_2 (7×50 ml). The combined organic layers were dried with MgSO₄, concentrated under reduced pressure and purified by column chromatography (SiO₂, Et₂O). The combined pure fractions were dried with MgSO₄ and evaporated under reduced pressure. **155** was obtained as a white amorphous solid (651 mg, 3.16 mmol, 64.1 %).

TLC R_f = 0.35 (EtOAc)

IR (neat) ν_{max} / cm⁻¹ = 3277.6 (N-H and O-H), 2962.2 (C-H), 2876.0 (C-H), 1636.3 (amide C=O)

¹H NMR (400 MHz, CDCl₃) δ / ppm = 6.12 (br s, 1 H, NH), 4.42 (br s, 1 H, OH), 3.94 (q, J = 6.6 Hz, 1 H, CHOH), 3.82 (tt, J = 8.4, 5.3 Hz, 1 H, CHNH), 3.60 (t, J = 6.2 Hz, 2 H, CH₂Cl), 2.38 (t, J = 7.2 Hz, 2 H, CH₂C=O), 2.05 - 2.16 (m, 3 H, CHHCHNH and CH₂CH₂Cl), 1.96 - 2.04 (m, 1 H, CHHCHOH), 1.74 - 1.85

(m, 1 H, CHCH₂CHOH), 1.58 - 1.73 (m, 2 H, CHCH₂CHOH and CHCHOH), 1.43 (dq, *J* = 12.7, 8.3 Hz, 1 H, CHCHNH)

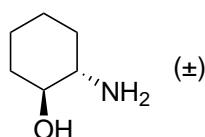
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 173.8 (C=O), 79.4 (CHOH), 60.6 (CHNH), 44.4 (CH₂Cl), 32.8 (CH₂C=O), 32.4 (CH₂CHOH), 30.1 (CH₂CHNH), 28.0 (CH₂CH₂Cl), 21.1 (CH₂CH₂CHOH)

HRMS (ESI⁺) *m/z* / Da = 228.0787, [M+Na]⁺ found, [C₉H₁₆ClNNaO₂]⁺ requires 228.0762

$[\alpha]_D^{20} / {}^\circ 10^{-1} \text{cm}^2 \text{g}^{-1} = -13.0$ (*c* / g(100 ml)⁻¹ = 0.5, MeOH)

The compound has not been reported previously.

5.65 (*trans*)-2-Aminocyclohexan-1-ol 157



Cyclohexene oxide **156** (10 ml, 9.70 g, 98.8 mmol, 1 eq.), NH₃ (90 ml, 35 % w/w aq., 27.7 g, 791 mmol, 8 eq.) and MeOH (100 ml) were stirred at r.t. for 72 h. The solvent was removed by blowing a stream of N₂ over it, followed by evaporation under high vacuum. **157** was obtained as a white amorphous solid (9.90 g, 85.2 mmol, 86.2 %)

TLC *R_f* = 0.04 (30 % MeOH/CH₂Cl₂)

IR (neat) ν_{max} / cm⁻¹ = 3350.4 (N-H), 3306.2 (br, O-H), 2926.9 (C-H), 2852.6 (C-H)

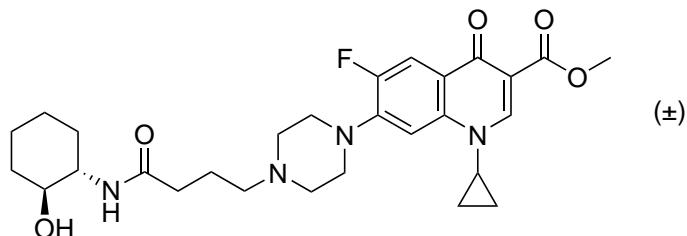
¹H NMR (400 MHz, CDCl₃) δ / ppm = 3.01 (td, *J* = 9.4, 4.8 Hz, 1 H, CHOH), 2.80 - 2.92 (m, 2 H, OH and NH₂), 2.35 (ddd, *J* = 11.1, 9.1, 4.1 Hz, 1 H, CHNH₂), 1.77 - 1.84 (m, 1 H, CHCHOH), 1.69 - 1.76 (m, 1 H, CHCHNH₂), 1.56 - 1.66 (m, 1 H, CHCH₂CHOH), 1.45 - 1.56 (m, 1 H, CHCH₂CHNH₂), 1.07 - 1.19 (m, 3 H, CHCH₂CHOH, CHCH₂CHNH₂ and CHCHOH), 0.94 - 1.05 (m, 1 H, CHCHNH₂)

¹³C NMR (101 MHz, CDCl₃) δ / ppm = 75.4 (CHOH), 56.6 (CHN₂), 33.8 (CH₂CHOH and CH₂CHN₂), 24.7 (CH₂CH₂CHNH₂), 24.6 (CH₂CH₂CHOH)

HRMS (ESI⁺) *m/z* / Da = 116.1070, [M+H]⁺ found, [C₆H₁₄NO]⁺ requires 116.1070

The data are consistent with the literature.¹⁷⁶

5.66 Methyl 1-cyclopropyl-6-fluoro-7-(4-((*trans*)-2-hydroxycyclohexyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 158



4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid trifluoroacetate **152** (200 mg, 0.367 mmol, 1 eq.), (*trans*)-2-aminocyclohexan-1-ol **157** (91.1 mg, 0.791 mmol, 2.1 eq.), 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide hydrochloride (112 mg, 0.584 mmol, 1.6 eq.), 1-hydroxybenzotriazole (96 mg, 0.710 mmol, 1.9 eq.) and DIPEA (192 μ l, 142 mg, 1.10 mmol, 3 eq.) were dissolved in DMF (5 ml) and stirred at r.t. for 16 h. The solvent was removed using a stream of N_2 and the residue was purified by preparative HPLC (5-50 % acetonitrile/water over 10 min). The combined pure fractions were evaporated under reduced pressure and then partitioned between $NaHCO_3$ (aq., sat., 10 ml) and CH_2Cl_2 (10 ml). The organic layer was dried with $MgSO_4$ and evaporated under reduced pressure. **158** was obtained as a white amorphous solid (61.2 mg, 0.116 mmol, 31.7 %).

IR (neat) ν_{max} / cm^{-1} = 3302.5 (N-H), 2929.8 (C-H), 2850.6 (C-H), 2832.9 (C-H), 1698.1 (ester C=O), 1646.4 (amide C=O), 1613.8 (quinolone C=O)

1H NMR (400 MHz, MeOD) δ / ppm = 8.60 (s, 1 H, *ortho* to C(=O)OCH₃), 7.79 (d, J = 13.5 Hz, 1 H, *ortho* to F), 7.46 (d, J = 7.2 Hz, 1 H, *meta* to F), 3.84 (s, 3 H, CH₃), 3.62 - 3.68 (m, 1 H, NCH(CH₂)₂), 3.58 (td, J = 10.3, 4.2 Hz, 1 H, CHNH), 3.38 (br s, 4 H, CH₂N(CH₂CH₂)CH₂CH₂), 3.32 - 3.36 (m, 1 H, CHOH), 2.83 (br s, 4 H, CH₂N(CH₂)CH₂), 2.60 (t, J = 7.3 Hz, 2 H, C(=O)CH₂CH₂CH₂N), 2.32 (td, J = 7.1, 3.1 Hz, 2 H, C(=O)CH₂), 1.96 - 2.04 (m, 1 H, CHHCHOH), 1.87 - 1.96 (m, 3 H, CHHCHNH and C(=O)CH₂CH₂), 1.72 - 1.77 (m, 1 H, CHHCH₂CHOH), 1.66 - 1.72 (m, 1 H, CHHCH₂CHNH), 1.25 - 1.39 (m, 5 H, CHHCHOH, CHHCH₂CHOH, CHHCH₂CHNH and NCH(CHH)₂), 1.15 - 1.25 (m, 3 H, CHHCHOH and NCH(CHH)₂)

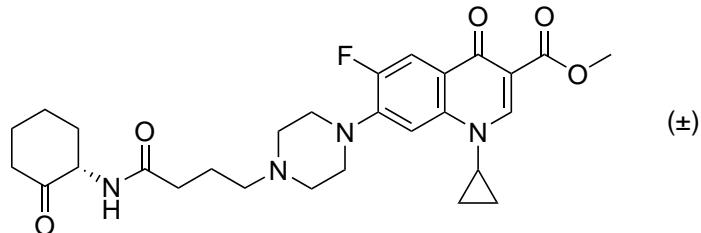
^{13}C NMR (101 MHz, MeOD) δ / ppm = 175.8 (CH₂C(=O)NH), 175.3 (C(=O)CC(=O)OCH₃), 166.8 (C(=O)OCH₃), 154.9 (d, J = 248.8 Hz, *ipso* to F), 150.2 (C=CC(=O)OCH₃), 146.1 (d, J = 10.8 Hz, *ipso* to piperazine), 139.9 (*para* to F), 123.5 (d, J = 7.5 Hz, *para* to piperazine), 113.2 (d, J = 23.2 Hz, *ortho* to C=O and *ortho* to F), 110.2 (CC(=O)OCH₃), 107.2 (*meta* to C=O and *meta* to F), 74.1 (CHOH), 58.9 (C(=O)CH₂CH₂CH₂N), 56.4 (CHNH), 54.0 (C(=O)CH₂CH₂CH₂N(CH₂)CH₂), 52.3 (CH₃), 50.5 (d, J = 5.0 Hz, C(=O)CH₂CH₂CH₂N(CH₂CH₂)CH₂), 36.4 (NCH(CH₂)₂), 35.7 (CH₂CHOH), 35.1 (C(=O)CH₂), 32.8 (CH₂CHNH), 25.9 (CH₂CH₂CHNH), 25.5 (CH₂CH₂CHOH), 23.5 (C(=O)CH₂CH₂), 8.7 (NCH(CH₂)₂)

^{19}F NMR (376.45 MHz, MeOD) δ / ppm = -124.7 (ciprofloxacin F)

HRMS (ESI⁺) m/z / Da = 529.2827, [M+H]⁺ found, [C₂₈H₃₈FN₄O₅]⁺ requires 529.2826

The compound has not been reported previously.

5.67 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxocyclohexyl)amino)-butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate **159**



Methyl 1-cyclopropyl-6-fluoro-7-(4-((*trans*)-2-hydroxycyclohexyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate **158** (5.2 mg, 9.84 μ mol, 1 eq.) and Dess-Martin periodinane (16.4 mg, 38.7 μ mol, 4 eq.) were stirred in CH_2Cl_2 (3 ml) at r.t. for 6 h. The solvent was removed under reduced pressure and the residue was purified by preparative HPLC (5-95 % acetonitrile/water over 20 min). The combined pure fractions were evaporated under reduced pressure to a volume of 20 ml, then NaHCO_3 (aq., sat., 30 ml) and 10 % *i*-PrOH/ CHCl_3 (30 ml) were added. The organic layer was dried with MgSO_4 and evaporated under reduced pressure. **159** was obtained as a white amorphous solid (3.6 mg, 6.8 μ mol, 69.1 %).

TLC R_f = 0.74 (30 % MeOH/ CH_2Cl_2)

IR (neat) ν_{max} / cm^{-1} = 2921.2 (C-H), 2851.6 (C-H), 1721.4 (ketone C=O), 1698.0 (ester C=O), 1639.3 (amide C=O), 1620.0 (quinolone C=O)

$^1\text{H NMR}$ (400 MHz, DMSO d₆) δ / ppm = 8.45 (s, 1 H, *ortho* to C(=O)OCH₃), 7.87 (d, J = 6.2 Hz, 1 H, NH), 7.76 (d, J = 13.4 Hz, 1 H, *ortho* to F), 7.44 (d, J = 7.5 Hz, 1 H, *meta* to F), 4.42 (dddd, J = 13.0, 7.6, 6.0, 1.0 Hz, 1 H, CH₂NH), 3.73 (s, 3 H, CH₃), 3.65 (tt, J = 7.1, 3.9 Hz, 1 H, NCH₂(CH₂)₂), 3.25 (br s, 4 H, CH₂N(CH₂CH₂)CH₂CH₂), 2.58 (br s, 4 H, CH₂N(CH₂)CH₂), 2.45 - 2.53 (m, 1 H, CH₂C(=O)CHNH), 2.36 (br s, 2 H, C(=O)CH₂CH₂CH₂N), 2.26 (dtt, J = 13.4, 2.6, 1.6 Hz, 1 H, CH₂C(=O)CHNH), 2.16 - 2.22 (m, 2 H, C(=O)CH₂CH₂CH₂N), 2.12 (ddq, J = 12.7, 6.0, 2.8 Hz, 1 H, CH₂CH₂CHNH), 2.00 (ddquin, J = 13.2, 6.0, 2.9 Hz, 1 H, CH₂CH₂C(=O)), 1.65 - 1.83 (m, 4 H, CH₂CH₂CHNH), 1.41 - 1.56 (m, 2 H, CH₂CH₂CHNH and CH₂CH₂C(=O)), 1.20 - 1.30 (m, 2 H, NCH(CHH)₂), 1.05 - 1.13 (m, 2 H, NCH(CHH)₂)

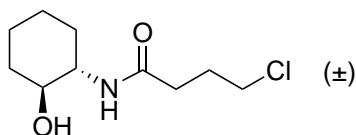
$^{13}\text{C NMR}$ (101 MHz, DMSO d₆) δ / ppm = 207.5 (C(=O)CHNH), 171.7 (C(=O)CC(=O)OCH₃), 171.6 (CH₂C(=O)NH), 165.0 (C(=O)OCH₃), 152.6 (d, J = 247.6 Hz, *ipso* to F), 148.3 (C=CC(=O)OCH₃), 143.9 (br s, *ipso* to piperazine), 138.1 (para to F), 121.8 (d, J = 6.4 Hz, para to piperazine), 111.5 (d, J = 22.4 Hz, *ortho* to C=O and *ortho* to F), 109.0 (CC(=O)OCH₃), 106.3 (*meta* to C=O and *meta* to F), 57.0 (CH₂NH and C(=O)CH₂CH₂CH₂N), 52.3 (br s, C(=O)CH₂CH₂CH₂N(CH₂)CH₂), 51.3 (CH₃), 49.5 (br s, C(=O)CH₂CH₂CH₂N(CH₂CH₂)CH₂), 40.6 (CH₂C(=O)CHNH), 34.8 (NCH(CH₂)₂), 33.9 (CH₂CH₂CHNH), 32.9 (C(=O)CH₂CH₂CH₂N), 27.2 (CH₂CH₂C(=O)CHNH), 23.8 (CH₂CH₂CHNH), 22.4 (br s, C(=O)CH₂CH₂CH₂N), 7.6 (NCH(CH₂)₂)

$^{19}\text{F NMR}$ (376.45 MHz, DMSO d₆) δ / ppm = -124.3 (ciprofloxacin F)

HRMS (ESI⁺) m/z / Da = 527.2654, [M+H]⁺ found, [C₂₈H₃₆FN₄O₅]⁺ requires 527.2670

The compound has not been reported previously.

5.68 4-Chloro-*N*-((*trans*)-2-hydroxycyclohexyl)butanamide 160



(*trans*)-2-Aminocyclohexan-1-ol **157** (1.04 g, 9.03 mmol, 1 eq.), TEA (1.65 ml, 1.20 g, 11.8 mmol, 1.3 eq.) and CH_2Cl_2 (50 ml) were stirred at 0 °C. 4-Chlorobutyryl chloride **153** (1.22 ml, 1.54 g, 10.9 mmol, 1.2 eq.) was added dropwise over 5 min. The mixture was stirred at 0 °C for 30 min, then water (50 ml) was added. The organic layer was separated off, and the aqueous layer was extracted with 10 % *i*-PrOH/CHCl₃ (2×50 ml). The combined organic layers were dried with MgSO₄, concentrated under reduced pressure and purified by column chromatography (SiO₂, 0-100 % EtOAc/Et₂O). The combined organic fractions were dried with MgSO₄ and evaporated under reduced pressure. **160** was obtained as white needles (1.51 g, 6.87 mmol, 76.1 %).

TLC R_f = 0.19 (Et₂O)

mp T / °C = 72.5-75.7 (*i*-PrOH, CHCl₃)

IR (neat) ν_{max} / cm⁻¹ = 3289.9 (N-H), 3250.0 (O-H), 2927.6 (C-H), 2857.1 (C-H), 1629.2 (amide C=O)

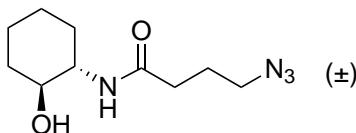
¹H NMR (400 MHz, MeOD) δ / ppm = 3.60 (t, J = 6.6 Hz, 2 H, CH_2Cl), 3.51 - 3.60 (m, 1 H, CH_2NH), 3.28 - 3.39 (m, 1 H, CHOH), 2.37 (td, J = 7.4, 2.3 Hz, 2 H, C(=O)CH₂), 2.06 (quin, J = 7.0 Hz, 2 H, C(=O)CH₂CH₂), 1.97 - 2.01 (m, 1 H, CH_2CHOH), 1.85 - 1.93 (m, 1 H, CH_2CHNH), 1.70 - 1.77 (m, 1 H, $\text{CH}_2\text{CH}_2\text{CHOH}$), 1.64 - 1.70 (m, 1 H, $\text{CH}_2\text{CH}_2\text{CHNH}$), 1.24 - 1.35 (m, 3 H, $\text{CH}_2\text{CH}_2\text{CHOH}$, $\text{CH}_2\text{CH}_2\text{CHNH}$ and $\text{CH}_2\text{CH}_2\text{CHOH}$), 1.13 - 1.25 (m, 1 H, CH_2CHNH_2)

¹³C NMR (101 MHz, MeOD) δ / ppm = 175.0 (C(=O)), 74.1 (CHOH), 56.3 (CH_2NH), 45.3 (CH_2Cl), 35.6 (CH_2CHOH), 34.5 (C(=O)CH₂), 32.7 (CH_2CHNH), 30.1 (C(=O)CH₂CH₂), 25.8 ($\text{CH}_2\text{CH}_2\text{CHNH}$), 25.5 ($\text{CH}_2\text{CH}_2\text{CHOH}$)

HRMS (ESI⁺) m/z / Da = 242.0925, [M+Na]⁺ found, [C₁₀H₁₈ClNNaO₂]⁺ requires 242.0924

The compound has not been reported previously.

5.69 4-Azido-*N*-((*trans*)-2-hydroxycyclohexyl)butanamide 161



4-Chloro-*N*-((*trans*)-2-hydroxycyclohexyl)butanamide **160** (345 mg, 1.57 mmol, 1 eq.) and NaN₃ (180 mg, 2.77 mmol, 1.75 eq.) were stirred in DMF (12 ml) at 50 °C for 16 h. Water (50 ml) and 10 % *i*-PrOH/CHCl₃ (50 ml) were added, and the organic layer was removed. The aqueous layer was extracted again with 10 % *i*-PrOH/CHCl₃ (50 ml) and the combined organic fractions were dried with MgSO₄. The solvent was evaporated under reduced pressure, and then by using a N₂ stream. **161** was obtained as large white prisms (347 mg, 1.53

mmol, 97.5 %).

TLC $R_f = 0.23$ (EtOAc)

mp $T / ^\circ\text{C} = 74.5\text{--}75.7$ (*i*-PrOH, CHCl₃)

IR (neat) $\nu_{max} / \text{cm}^{-1} = 3299.0$ (N-H), 3207.8 (O-H), 2944.3 (C-H), 2927.9 (C-H), 2859.2 (C-H), 2089.2 (azide), 1624.0 (amide C=O)

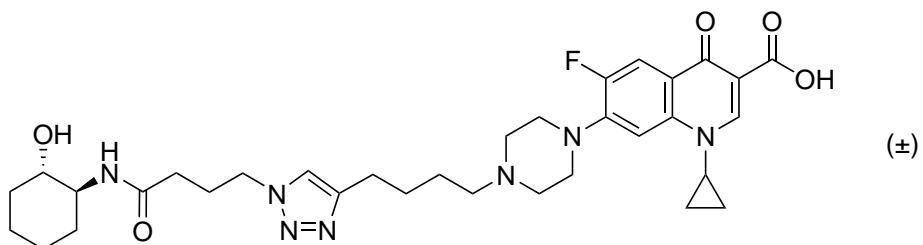
¹H NMR (400 MHz, MeOD) $\delta / \text{ppm} = 7.87$ (d, $J = 7.9$ Hz, 1 H, NH), 5.27 (d, $J = 4.3$ Hz, 1 H, OH), 3.56 (td, $J = 10.5, 4.4$ Hz, 1 H, CHNH), 3.28 - 3.41 (m, 3 H, CHOH and CH₂N₃), 2.30 (td, $J = 7.4, 2.7$ Hz, 2 H, C(=O)CH₂), 1.95 - 2.03 (m, 1 H, CHHCHOH), 1.87 (m, 3 H, C(=O)CH₂CH₂ and CHHCHNH), 1.70 - 1.76 (m, 1 H, CHHCH₂CHOH), 1.63 - 1.70 (m, 1 H, CHHCH₂CHNH), 1.25 - 1.38 (m, 3 H, CHHCH₂CHOH, CHHCH₂CHNH and CHHCHOH), 1.14 - 1.24 (m, 1 H, CHHCHNH₂)

¹³C NMR (101 MHz, MeOD) $\delta / \text{ppm} = 175.1$ (C(=O)), 74.0 (CHOH), 56.3 (CHNH), 52.0 (CH₂N₃), 35.5 (CH₂CHOH), 34.3 (C(=O)CH₂), 32.7 (CH₂CHNH), 26.3 (C(=O)CH₂CH₂), 25.8 (CH₂CH₂CHNH), 25.5 (CH₂CH₂CHOH)

HRMS (ESI⁺) $m/z / \text{Da} = 249.1331$, [M+Na]⁺ found, [C₁₀H₁₈N₄NaO₂]⁺ requires 249.1327

The compound has not been reported previously.

5.70 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-((trans)-2-hydroxycyclohexyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-ylbutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 162



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **76** (40 mg, 97.2 μmol , 1 eq.) and 4-azido-*N*-((*trans*)-2-hydroxycyclohexyl)butanamide **161** (22.0 mg, 97.2 μmol , 1 eq.) were dissolved in 10 % water/*t*-BuOH (3 ml), and the mixture was degassed by bubbling N₂ through it. A solution of CuSO₄ and THPTA (97.2 μl , 9.72 μmol , 0.1 eq. 100 mM, aq.) was added, followed by a solution of sodium ascorbate (194 μl , 19.4 μmol , 0.2 eq., 100 mM, aq.). The mixture was stirred at r.t. under argon for 16 h. Water (50 ml) and 10 % *i*-PrOH/CHCl₃ (50 ml) were added, then the organic layer was separated, dried with MgSO₄ and evaporated under reduced pressure. The residue was purified by preparative HPLC (5-70 % acetonitrile/water over 15 min). The combined pure fractions were evaporated under reduced pressure and then partitioned between NaHCO₃ (aq., sat., 50 ml) and 10 % *i*-PrOH/CHCl₃ (50 ml). The organic layer was dried with MgSO₄ and evaporated under reduced pressure. **162** was obtained as a white amorphous solid (30.3 mg, 47.5 μmol , 48.9 %).

IR (neat) ν_{max} / cm^{-1} = 3345.4 (N-H), 2927.6 (C-H), 2859.6 (C-H), 2814.7 (C-H), 1727.0 (carboxylic acid C=O), 1641.7 (amide C=O), 1625.8 (quinolone C=O), 1619.0 (triazole)

¹H NMR (400 MHz, DMSO d₆) δ / ppm = 8.64 (s, 1 H, *ortho* to C(=O)OH), 7.86 (d, J = 13.9 Hz, 1 H, *ortho* to F), 7.84 (s, 1 H, CH=CCH₂), 7.64 (d, J = 8.1 Hz, 1 H, NH), 7.54 (d, J = 7.5 Hz, 1 H, *meta* to F), 4.54 (d, J = 4.7 Hz, 1 H, OH), 4.30 (t, J = 6.8 Hz, 2 H, C(=O)CH₂CH₂CH₂N), 3.77 - 3.86 (m, 1 H, NCH(CH₂)₂), 3.33 - 3.40 (m, 1 H, CH₂NH), 3.31 (br t, J = 4.8 Hz, 4 H, CH=CCH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 3.14 - 3.24 (m, 1 H, CH₂OH), 2.63 (t, J = 7.4 Hz, 2 H, CH=CCH₂), 2.56 (br t, J = 4.6 Hz, 4 H, CH=CCH₂CH₂CH₂N(CH₂)CH₂), 2.38 (t, J = 6.9 Hz, 2 H, CH=CCH₂CH₂CH₂N), 2.04 - 2.08 (m, 2 H, C(=O)CH₂CH₂CH₂N), 1.96 - 2.04 (m, 2 H, C(=O)CH₂CH₂CH₂N), 1.78 - 1.87 (m, 1 H, CH₂CHOH), 1.69 - 1.78 (m, 1 H, CH₂CH₂NH), 1.63 (quin, J = 7.5 Hz, 2 H, CH=CCH₂CH₂CH₂N), 1.54 - 1.60 (m, 2 H, CH₂CH₂OH), 1.51 (quin, J = 7.4 Hz, 2 H, CH=CCH₂CH₂CH₂N), 1.28 - 1.35 (m, 2 H, NCH(CH₂)₂), 1.11 - 1.22 (m, 5 H, NCH(CH₂)₂, CH₂CHOH, CH₂CH₂CHOH and CH₂CH₂CH₂NH), 1.04 - 1.13 (m, 1 H, CH₂CH₂NH)

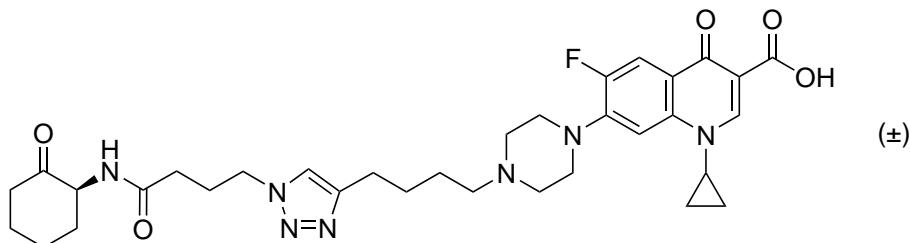
¹³C NMR (101 MHz, DMSO d₆) δ / ppm = 176.4 (C(=O)CC(=O)OH), 170.9 (CH₂C(=O)NH), 166.0 (C(=O)OH), 153.1 (d, J = 252.1 Hz, *ipso* to F), 148.0 (C=CC(=O)OH), 146.9 (CH=CCH₂), 145.3 (d, J = 10.0 Hz, *ipso* to piperazine), 139.2 (para to F), 121.8 (NCH=CCH₂), 118.5 (d, J = 8.3 Hz, para to piperazine), 110.9 (d, J = 23.2 Hz, *ortho* to C=O and *ortho* to F), 106.7 (CC(=O)OH), 106.3 (d, J = 3.3 Hz, *meta* to C=O and *meta* to F), 71.4 (CHOH), 57.4 (CH=CCH₂CH₂CH₂N), 54.2 (CH₂NH), 52.4 (CH=CCH₂CH₂CH₂N(CH₂)CH₂), 49.5 (CH=CCH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 49.5 (CH=CCH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 48.8 (C(=O)CH₂CH₂NCH=C), 35.9 (NCH(CH₂)₂), 34.1 (CH₂CHOH), 32.3 (C(=O)CH₂CH₂NCH=C), 31.1 (CH₂CH₂NH), 26.9 (CH=CCH₂CH₂CH₂N), 26.1 (C(=O)CH₂CH₂NCH=C), 25.8 (CH=CCH₂CH₂CH₂N), 25.0 (CH=CCH₂CH₂CH₂N), 24.2 (CH₂CH₂CH₂NH), 23.8 (CH₂CH₂CHOH), 7.6 (NCH(CH₂)₂)

¹⁹F NMR (376.45 MHz, DMSO d₆) δ / ppm = -121.4 (ciprofloxacin F)

HRMS (ESI⁺) m/z / Da = 638.3480, [M+H]⁺ found, [C₃₃H₄₅FN₇O₅]⁺ requires 638.3466

The compound has not been reported previously.

5.71 1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(4-oxo-4-((2-oxocyclohexyl)amino)butyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 163



1-Cyclopropyl-6-fluoro-7-(4-(4-((*trans*)-2-hydroxycyclohexyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-ylbutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **162** (15.0 mg, 23.6 mmol, 1 eq.) and Dess-Martin periodinane (35.0 mg, 82.5 mmol, 3.5 eq.) were stirred in CH₂Cl₂ (3 ml) at r.t. for 4 h. The solvent was removed under reduced pressure and the residue was purified by preparative HPLC (5-70 % acetonitrile/water over 15 min). The combined pure fractions were evaporated under reduced pressure, then NaHCO₃ (aq., sat., 30 ml)

and 10 % *i*-PrOH/CHCl₃ (30 ml) were added. The organic layer was dried with MgSO₄ and evaporated under reduced pressure. **163** was obtained as a clear gum (11.7 mg, 18.4 μ mol, 78.0 %).

IR (neat) ν_{max} / cm⁻¹ = 2941.2 (C-H), 2859.8 (C-H), 1719.8 (carboxylic acid C=O and ketone C=O), 1656.8 (amide C=O), 1625.6 (quinolone C=O), 1613.5 (triazole)

¹H NMR (500 MHz, DMSO d₆) δ / ppm = 8.65 (s, 1 H, *ortho* to C(=O)OH), 7.94 (d, *J* = 7.7 Hz, 1 H, NH), 7.88 (d, *J* = 13.4 Hz, 1 H, *ortho* to F), 7.85 (s, 1 H, CH=CCH₂), 7.55 (d, *J* = 7.3 Hz, 1 H, *meta* to F), 4.40 (dd, *J* = 12.8, 7.6, 6.1, 1.1 Hz, 1 H), 4.31 (t, *J* = 7.0 Hz, 1 H, C(=O)CH₂CH₂CH₂NH), 4.31 (t, *J* = 6.9 Hz, 1 H, C(=O)CH₂CH₂CH₂N), 3.74 - 3.84 (m, 1 H, NCH(CH₂)₂), 3.31 (br. s, 4 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.64 (t, *J* = 7.5 Hz, 2 H, CH=CCH₂), 2.56 (br t, *J* = 5.0, 5.0 Hz, 4 H, CH₂CH₂CH₂N(CH₂)CH₂), 2.45 - 2.52 (m, 1 H, CHHC(=O)), 2.38 (t, *J* = 7.1 Hz, 2 H, CH=CCH₂CH₂CH₂N), 2.25 (dtt, *J* = 13.4, 2.6, 1.6 Hz, 1 H, CHHC(=O)), 2.07 - 2.17 (m, 3 H, C(=O)CH₂CH₂CH₂N and CHHCHNH), 1.96 - 2.05 (m, 3 H, C(=O)CH₂CH₂CH₂N and CHHCH₂C(=O)), 1.68 - 1.81 (m, 2 H, CHHCH₂CHNH), 1.64 (quin, *J* = 7.5 Hz, 2 H, CH=CCH₂CH₂CH₂N), 1.40 - 1.56 (m, 5 H, CHHCH₂C(=O), CHHCHNH and CH=CCH₂CH₂CH₂N), 1.27 - 1.34 (m, 2 H, NCH(CHH)₂), 1.13 - 1.20 (m, 2 H, NCH(CHH)₂)

¹³C NMR (126 MHz, DMSO d₆) δ / ppm = 207.4 (C(=O)CHNH), 176.3 (C(=O)CC(=O)OH), 170.8 (CH₂C(=O)NH), 166.0 (C(=O)OH), 153.0 (d, *J* = 246.4 Hz, *ipso* to F), 147.9 (C=CC(=O)OH), 146.8 (CH=CCH₂), 145.1 (d, *J* = 10.1 Hz, *ipso* to piperazine), 139.1 (*para* to F), 121.7 (NCH=CCH₂), 118.7 (d, *J* = 6.9 Hz, *para* to piperazine), 110.9 (d, *J* = 23.0 Hz, *ortho* to C=O and *ortho* to F), 106.3 (CC(=O)OH, and *meta* to C=O and *meta* to F), 57.3 (CH=CCH₂CH₂CH₂N), 57.0 (CHNH), 52.4 (CH₂CH₂CH₂N(CH₂)CH₂), 49.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂), 49.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂), 48.7 (C(=O)CH₂CH₂CH₂NCH=C), 40.5 (CH₂C(=O)), 35.8 (NCH(CH₂)₂), 33.7 (CH₂CHNH), 31.8 (C(=O)CH₂CH₂CH₂NCH=C), 27.1 (CH₂CH₂C(=O)), 26.9 (CH=CCH₂CH₂CH₂N), 26.0 (C(=O)CH₂CH₂CH₂NCH=C), 25.7 (CH=CCH₂CH₂CH₂N), 24.9 (CH=CCH₂CH₂CH₂N), 23.8 (CH₂CH₂CHNH), 7.6 (NCH(CH₂)₂)

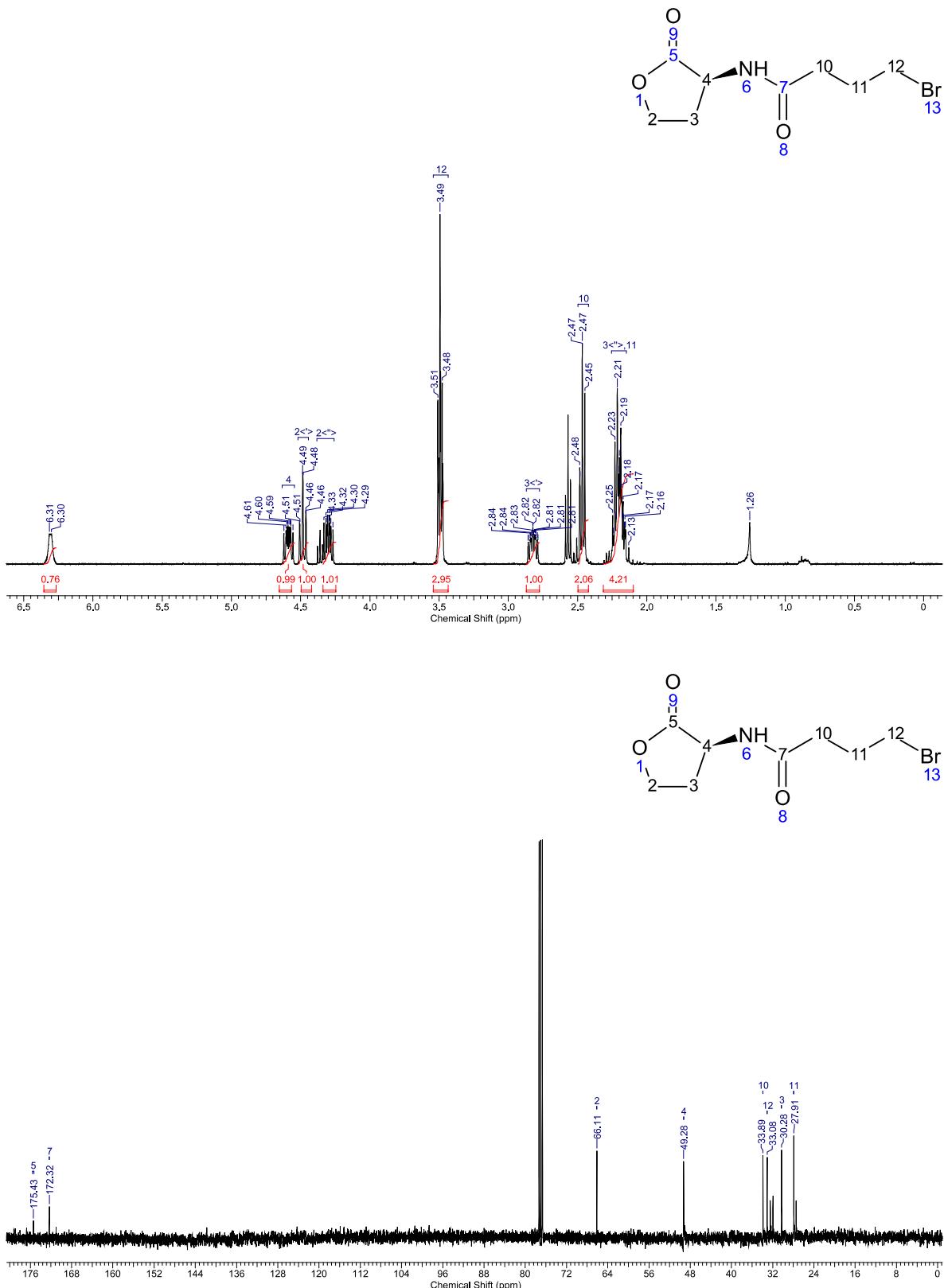
¹⁹F NMR (376 MHz, DMSO d₆) δ / ppm = -121.7 (s, ciprofloxacin F)

HRMS (ESI⁺) *m/z* / Da = 636.3303, [M+H]⁺ found, [C₃₃H₄₃FN₇O₅]⁺ requires 636.3310

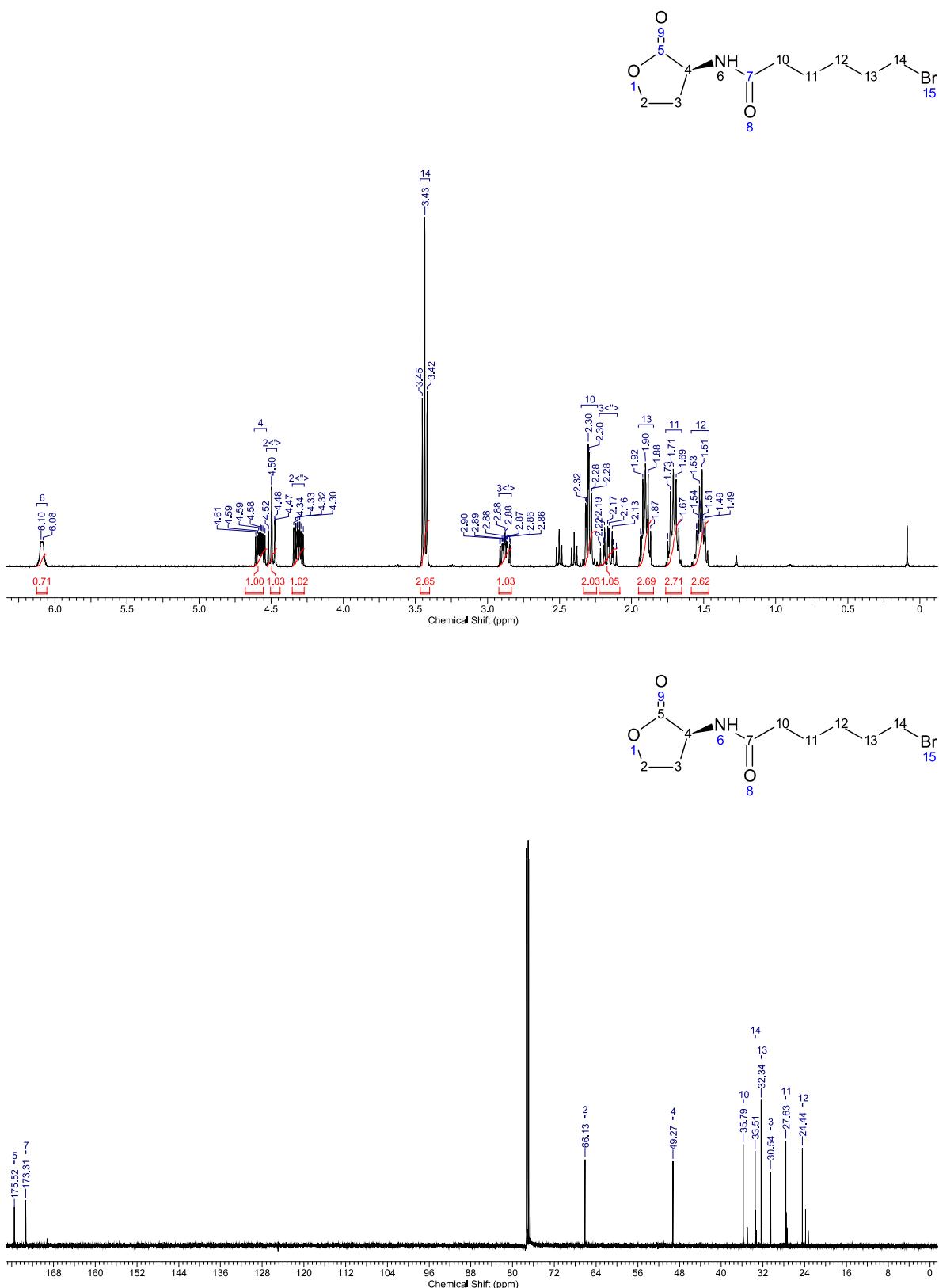
The compound has not been reported previously.

6 NMR spectra

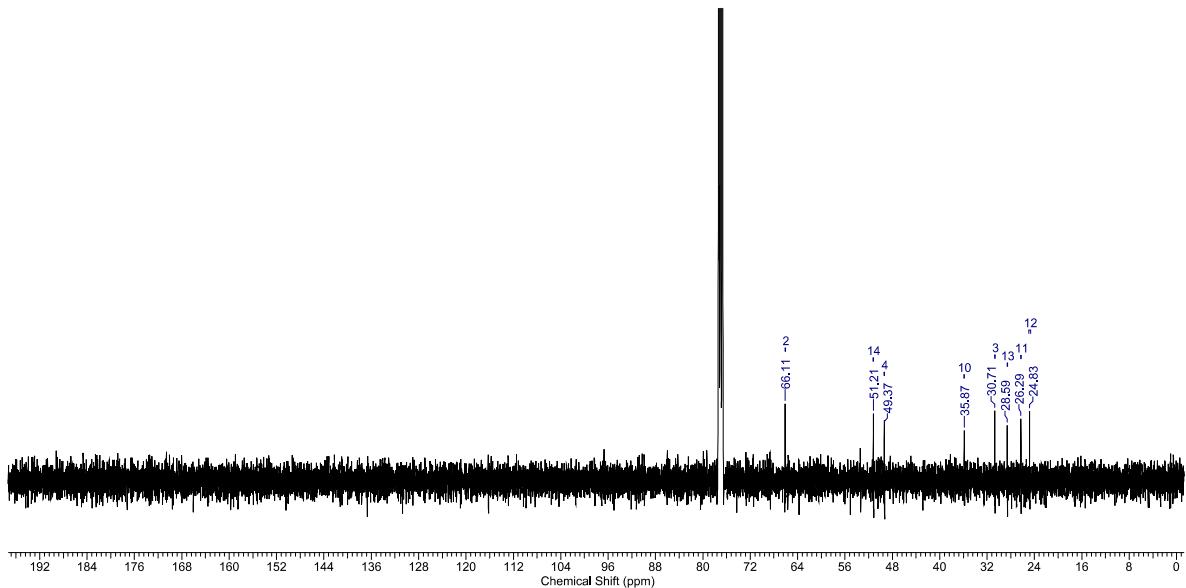
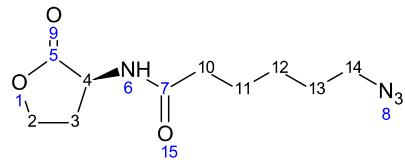
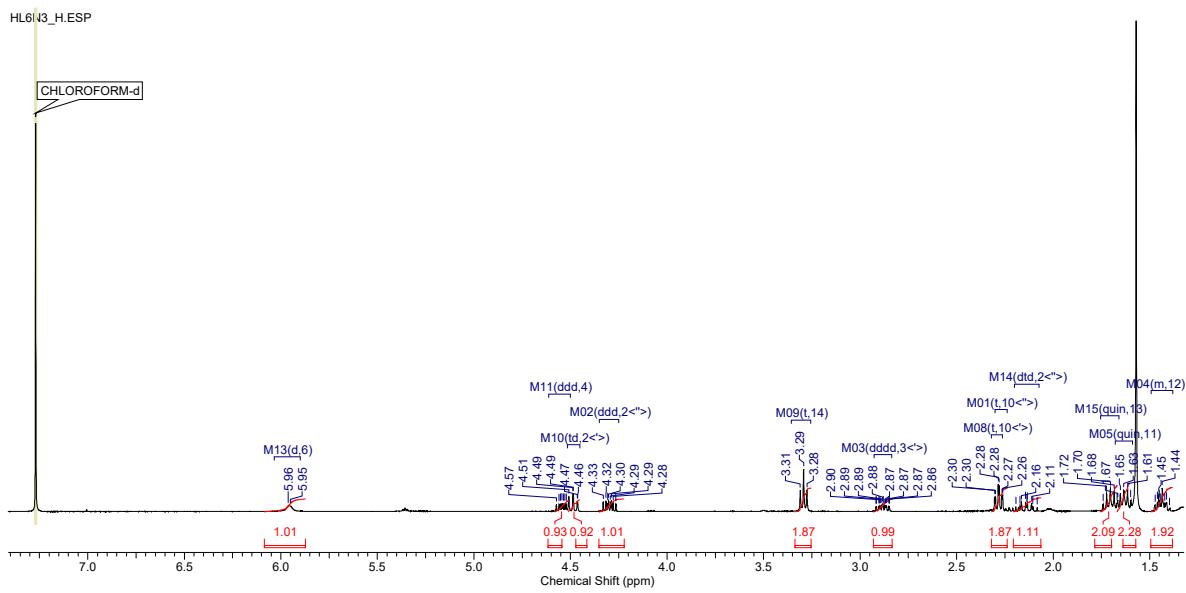
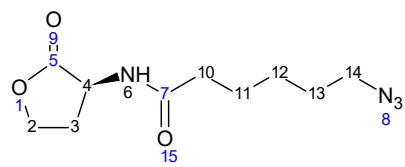
6.1 (*S*)-4-Bromo-*N*-(2-oxotetrahydrofuran-3-yl)butanamide 65



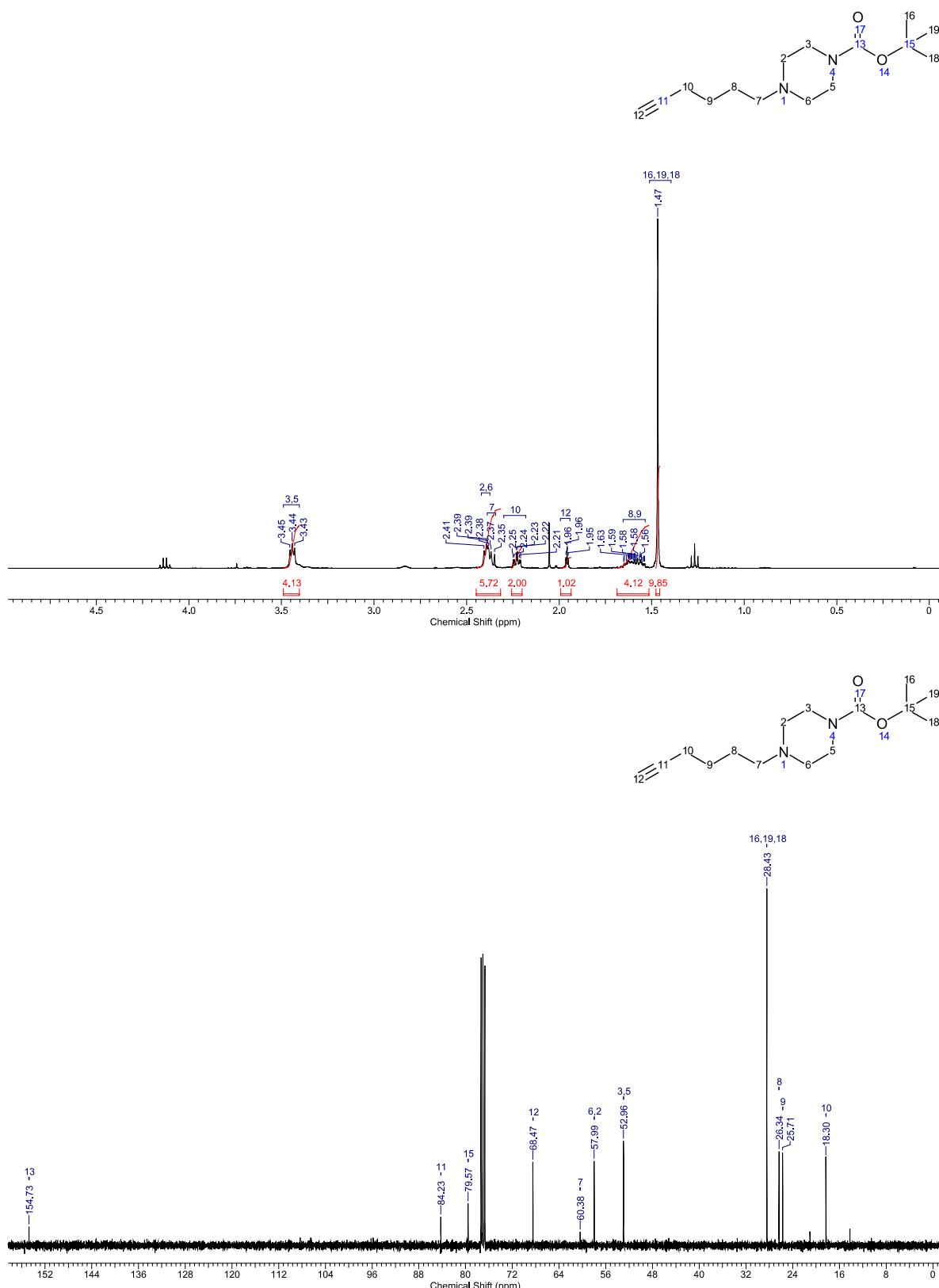
6.2 (*S*)-6-Bromo-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide 68



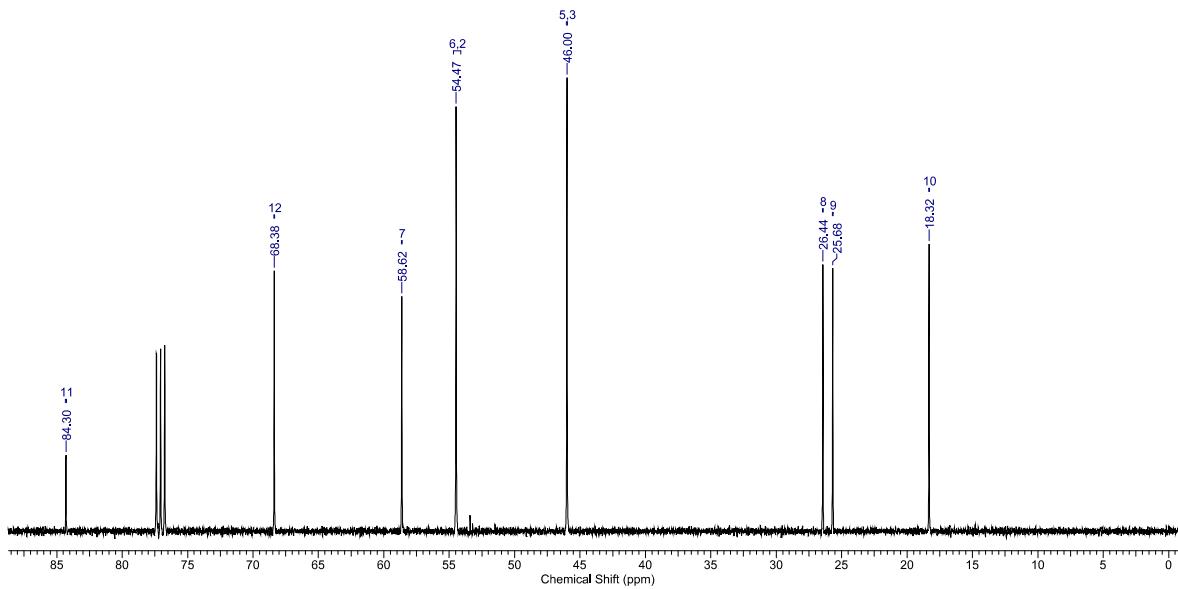
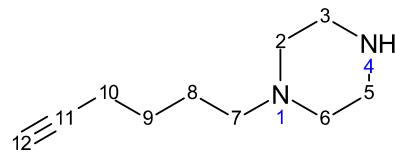
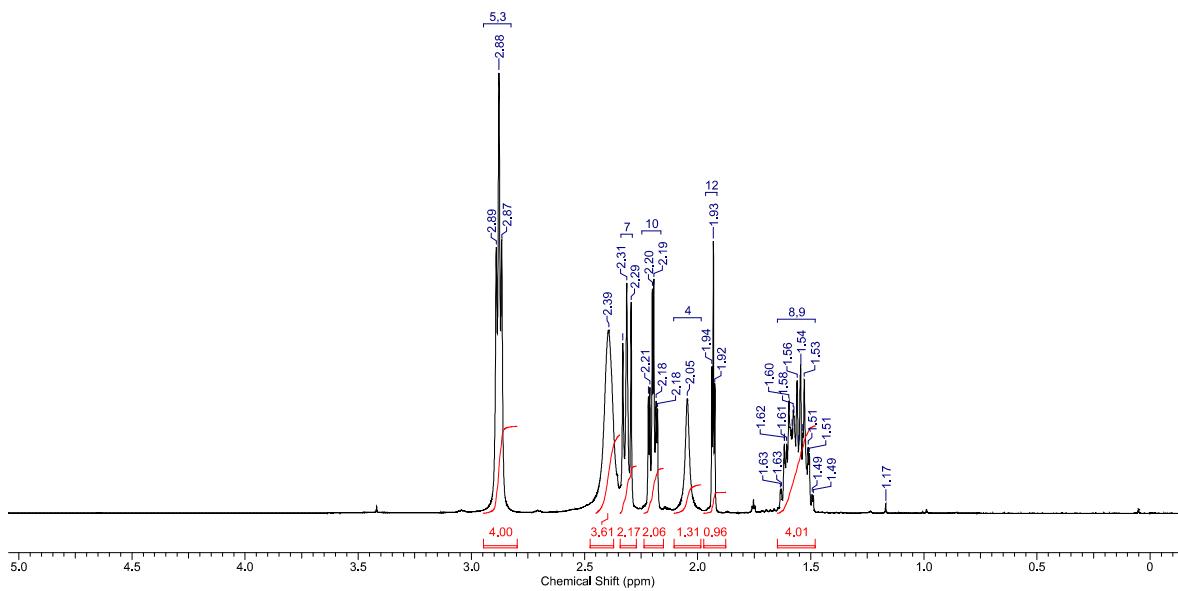
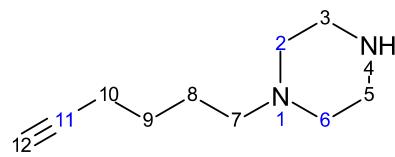
6.3 (S)-6-Azido-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide 69



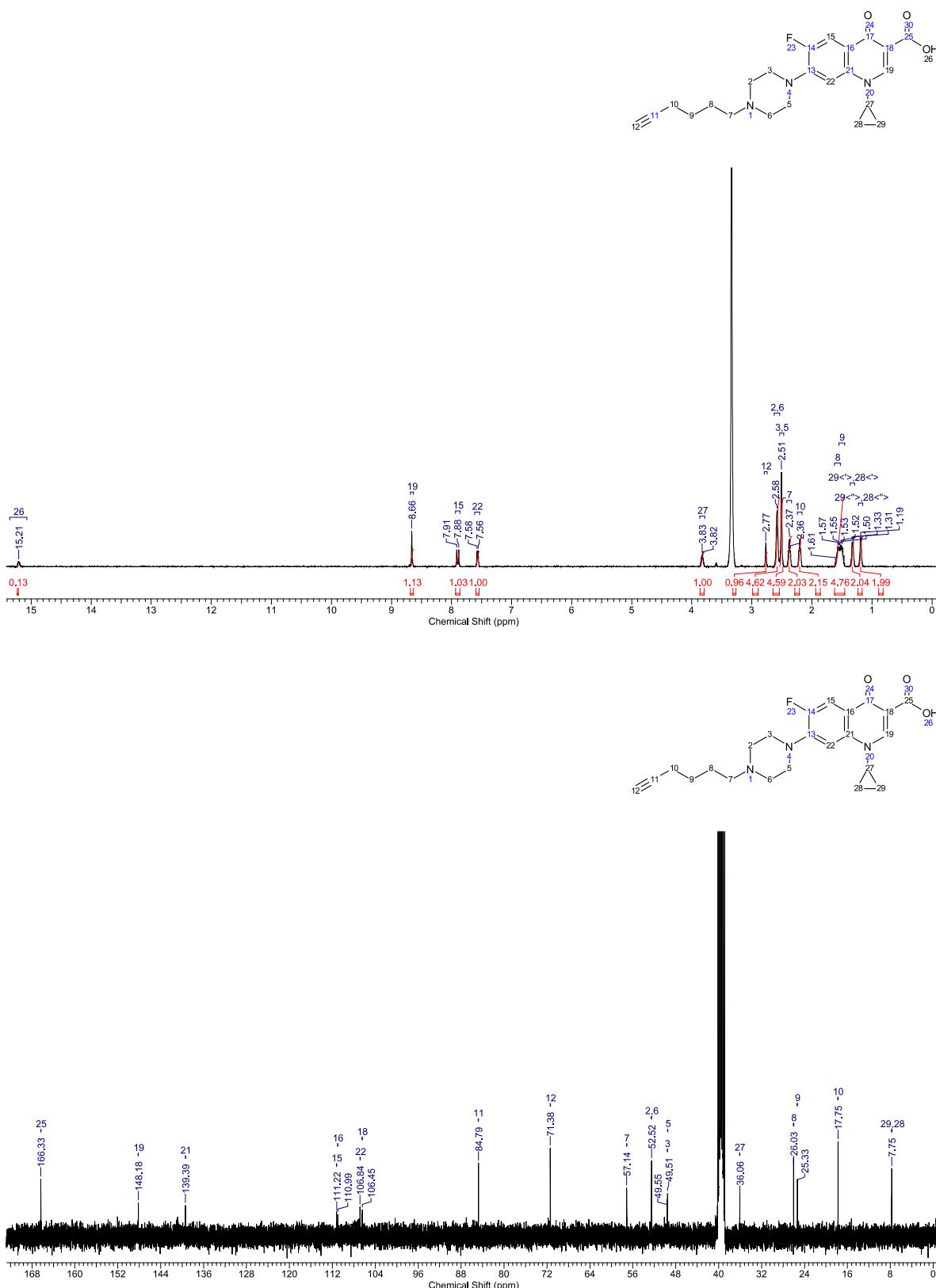
6.4 *tert*-Butyl 4-(hex-5-yn-1-yl)piperazine-1-carboxylate 73



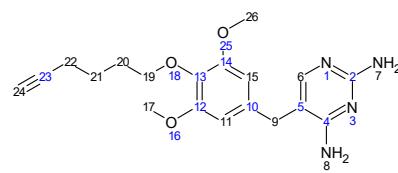
6.5 1-(Hex-5-yn-1-yl)piperazine 74



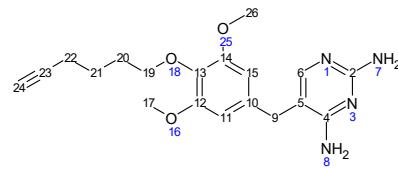
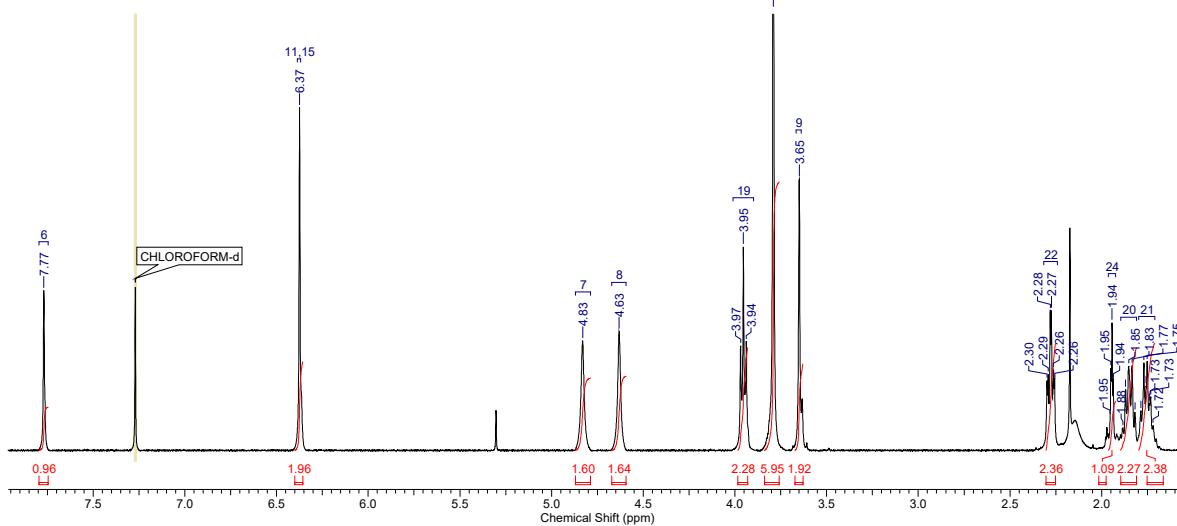
6.6 1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 76



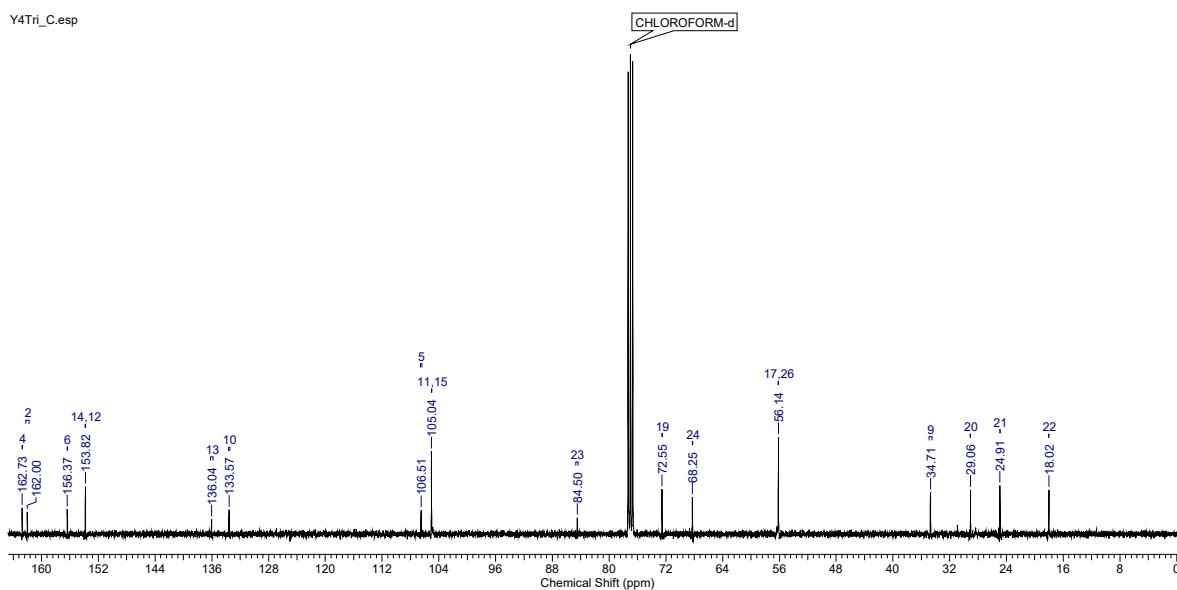
6.7 5-(4-(Hex-5-yn-1-yloxy)-3,5-dimethoxybenzyl)pyrimidine-2,4-diamine 79



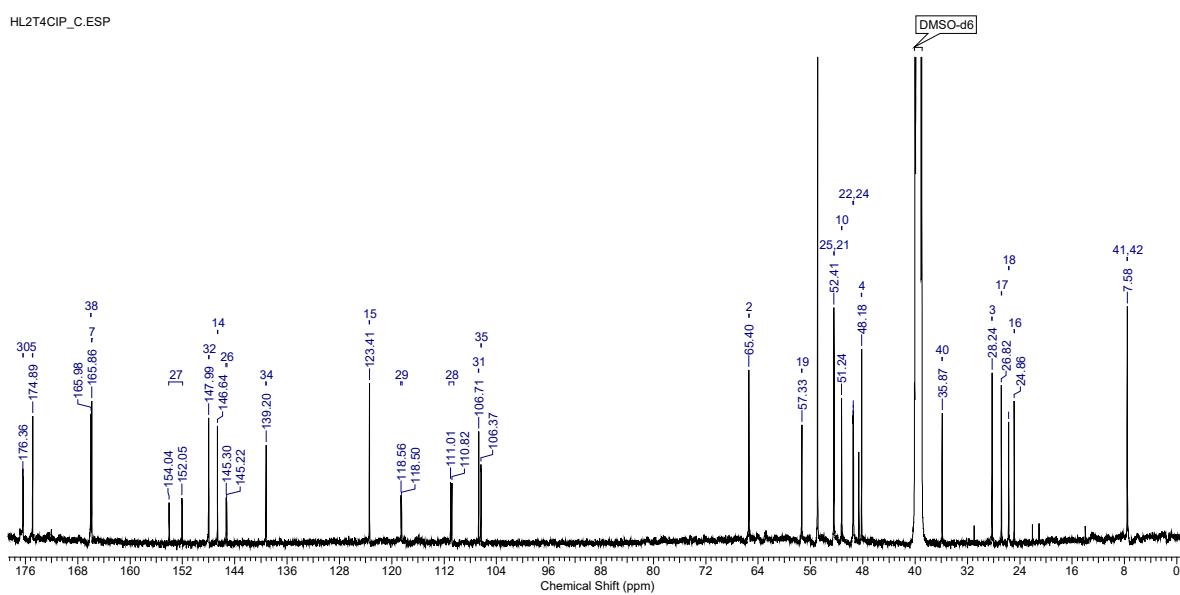
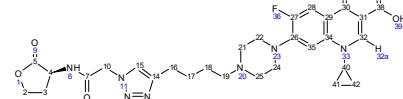
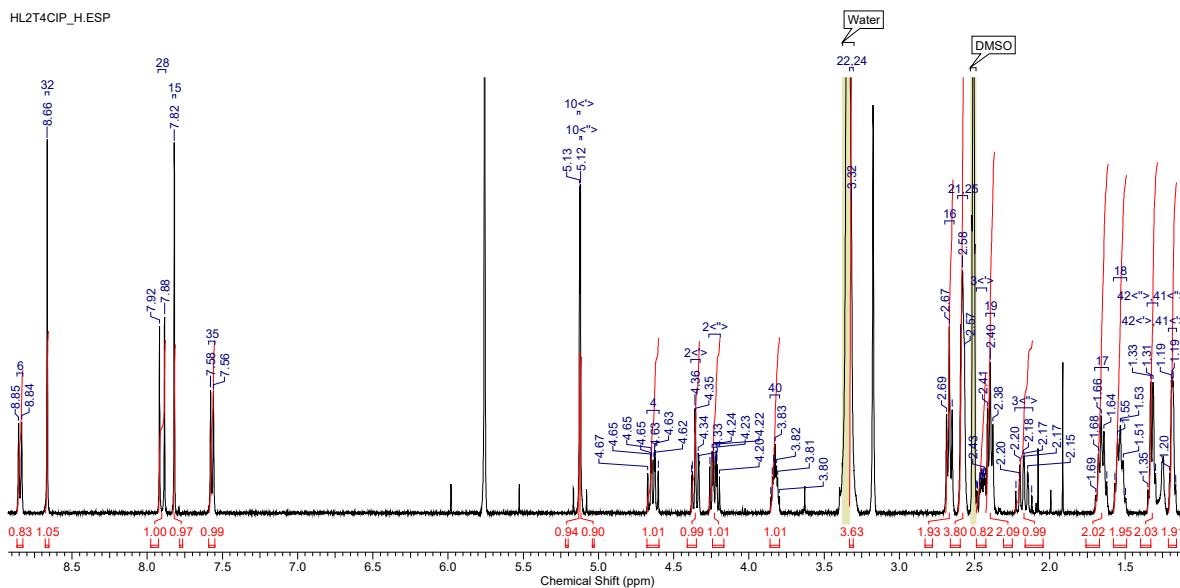
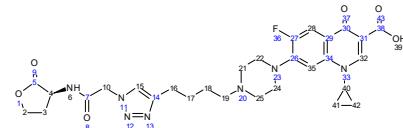
Y4Tri_H.esp



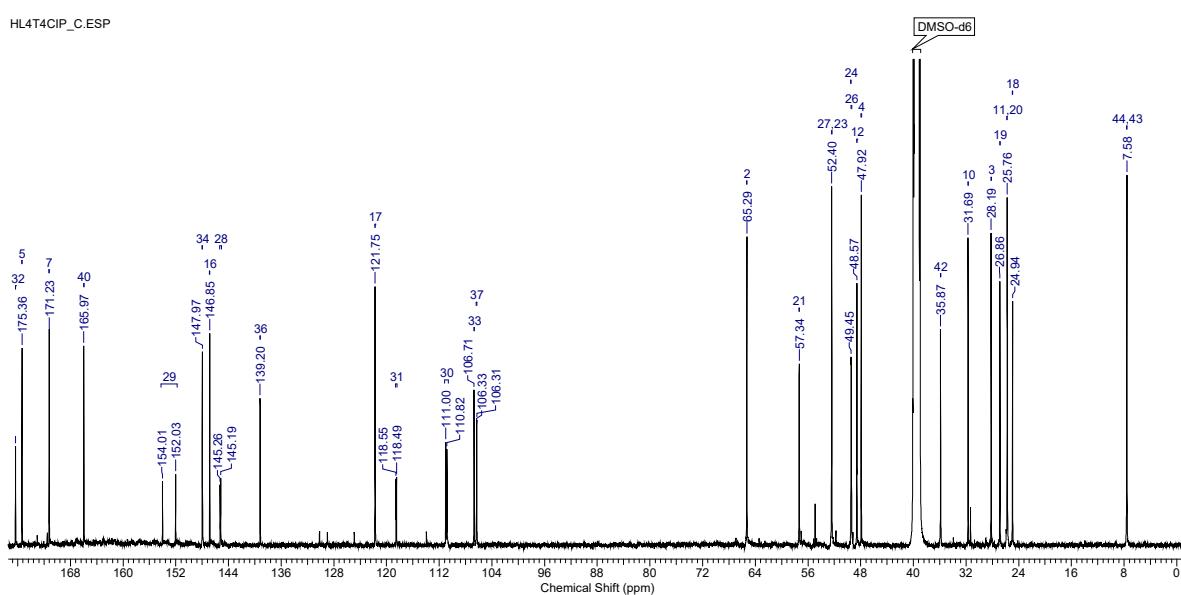
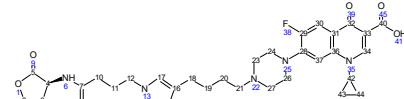
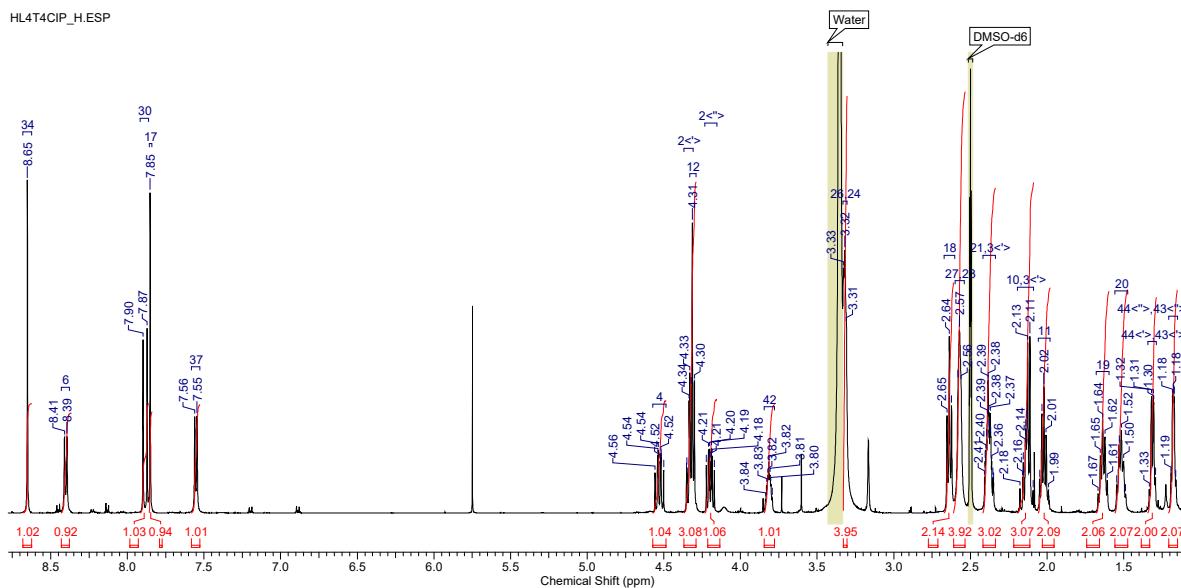
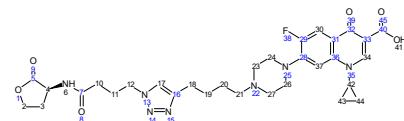
Y4Tri_C.esp



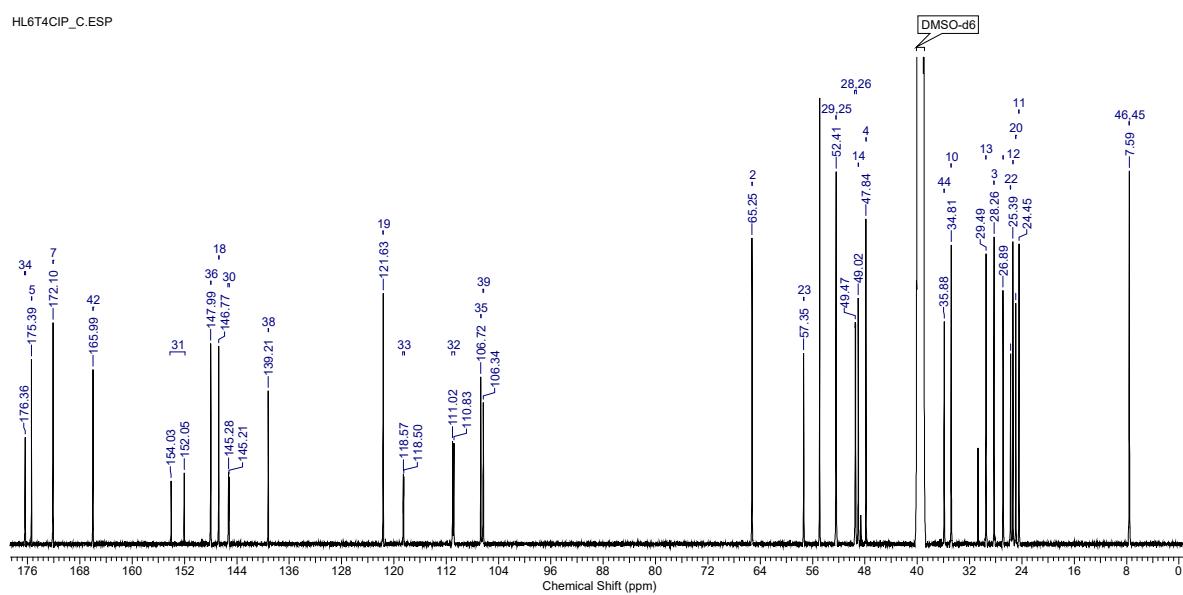
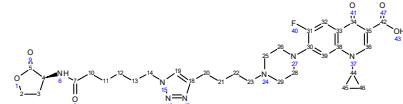
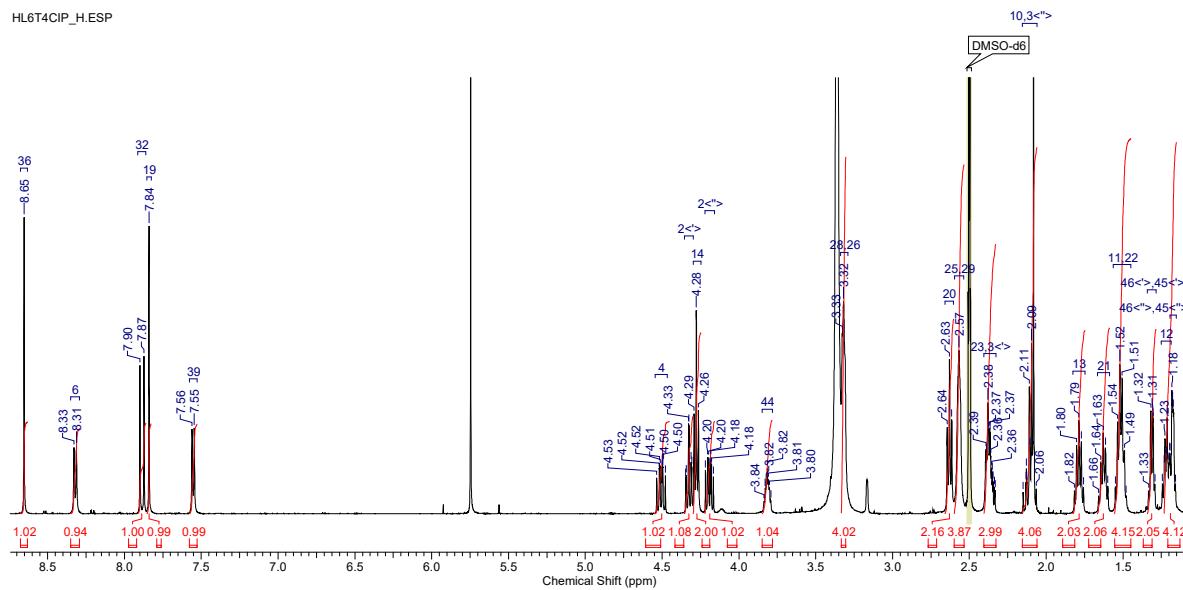
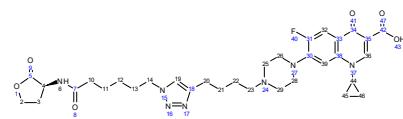
6.8 (S)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(2-oxo-2-((2-oxotetrahydrofuran-3-yl)amino)ethyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 80



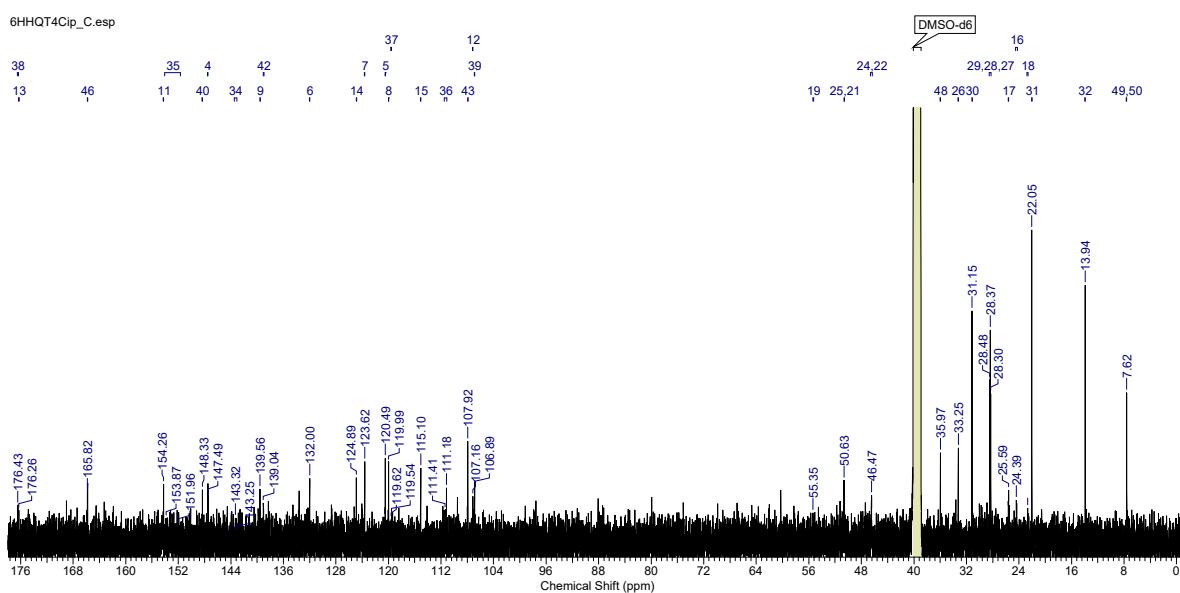
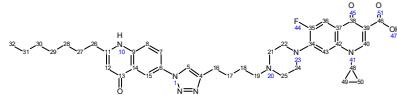
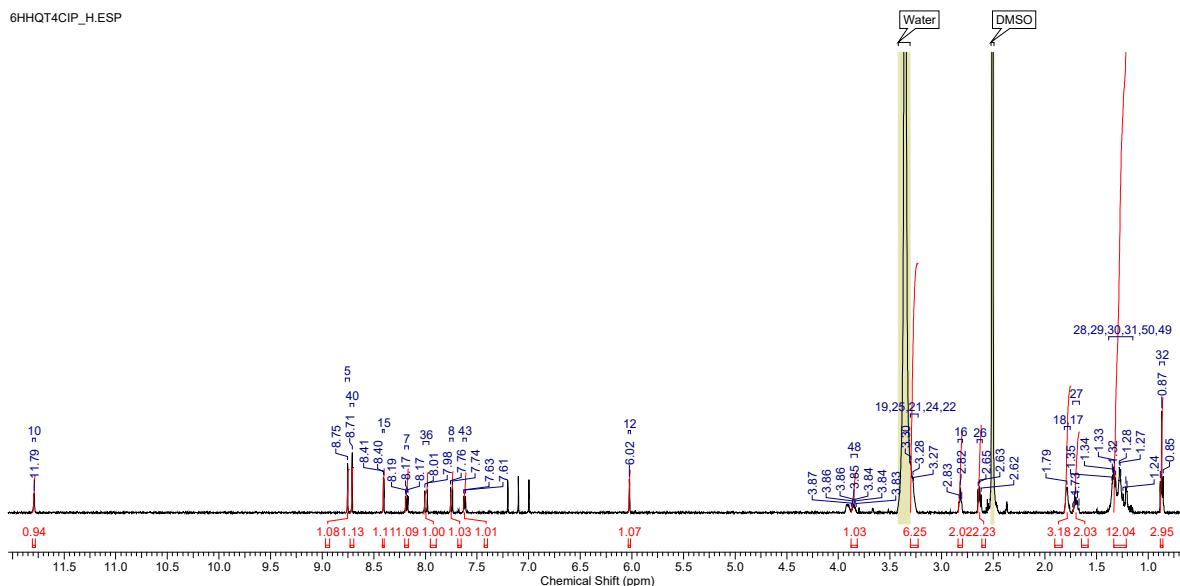
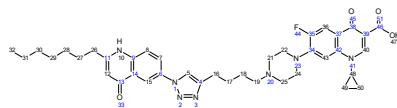
6.9 (*S*)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(4-oxo-4-((2-oxotetrahydrofuran-3-yl)amino)butyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 85



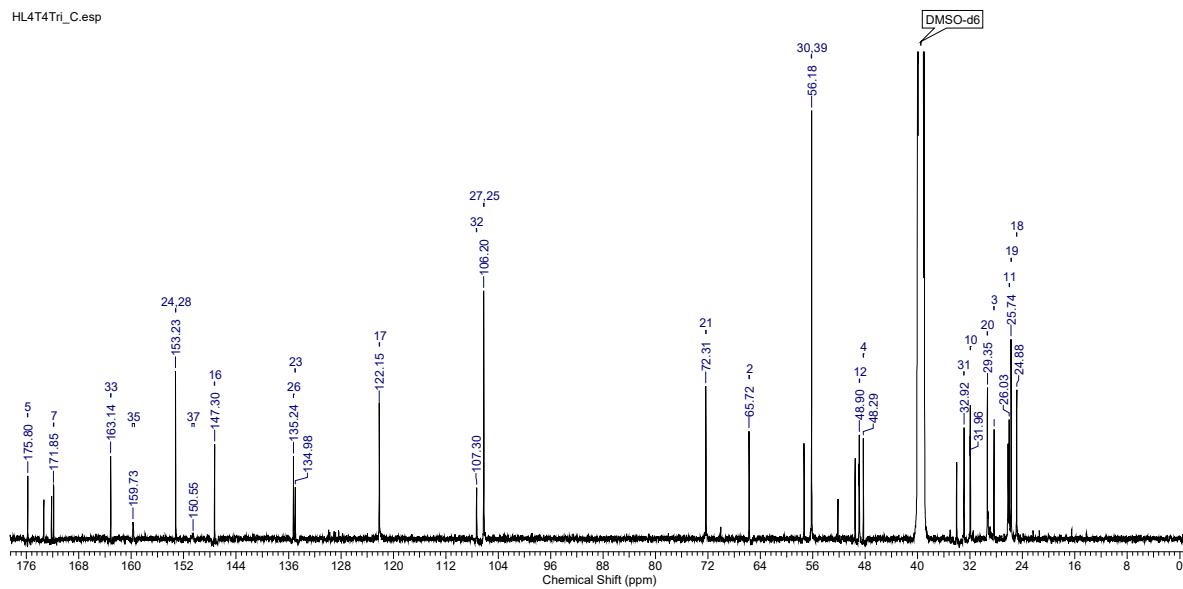
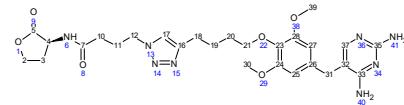
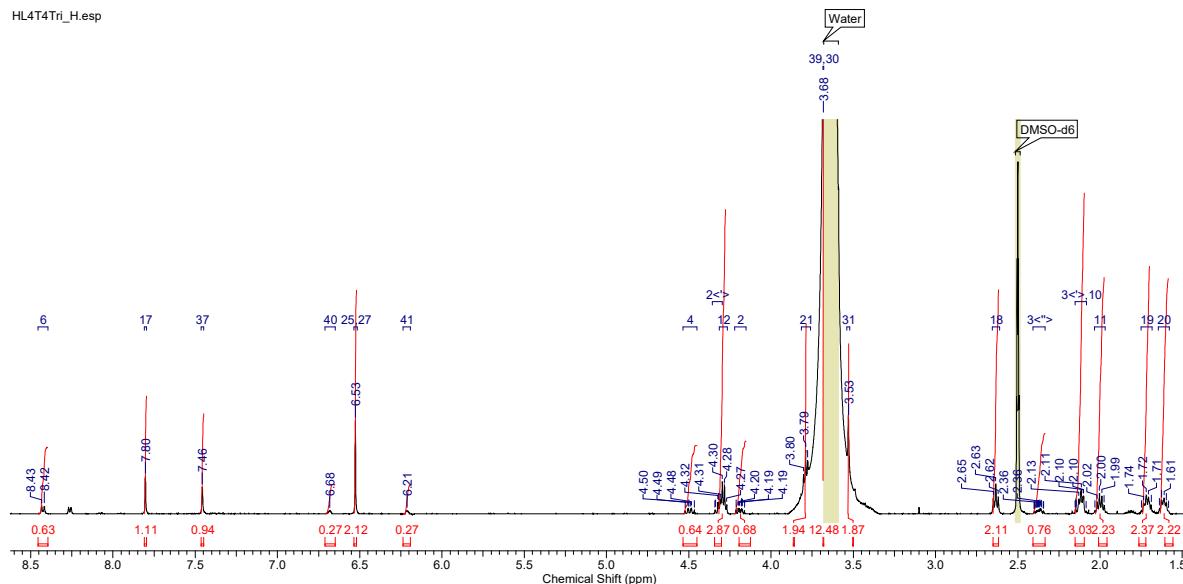
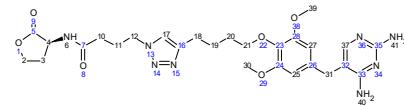
6.10 (*S*)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(6-oxo-6-((2-oxotetrahydrofuran-3-yl)amino)hexyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 86



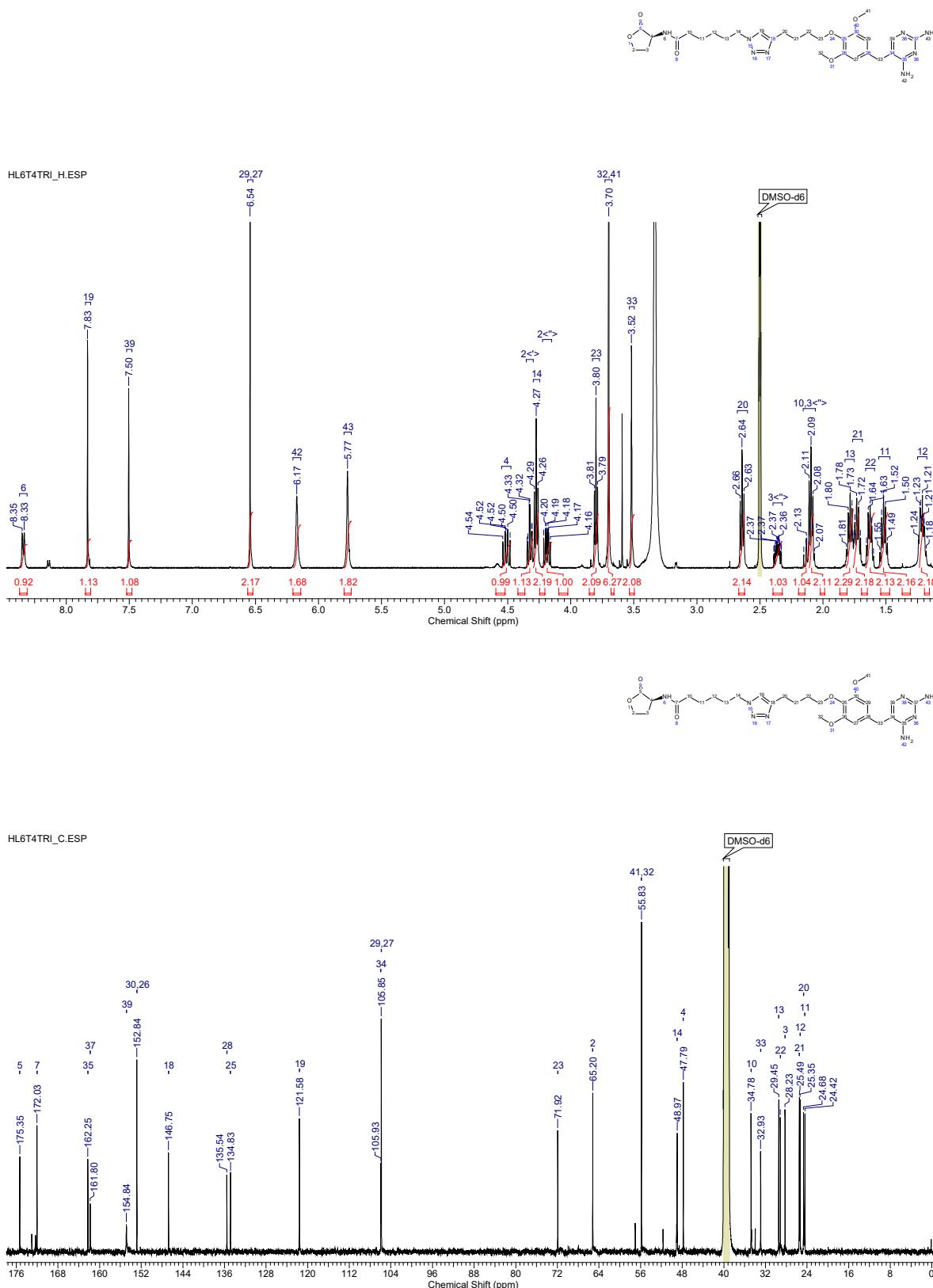
6.11 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(2-heptyl-4-oxo-1,4-dihydroquinolin-6-yl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 88



6.12 (*S*)-4-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1*H*-1,2,3-triazol-1-yl)-*N*-(2-oxotetrahydrofuran-3-yl)butanamide 92

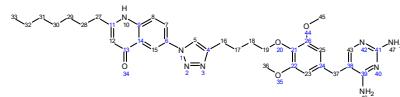


6.13 (*S*)-6-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl-1*H*-1,2,3-triazol-1-yl)-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide 93

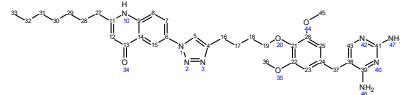
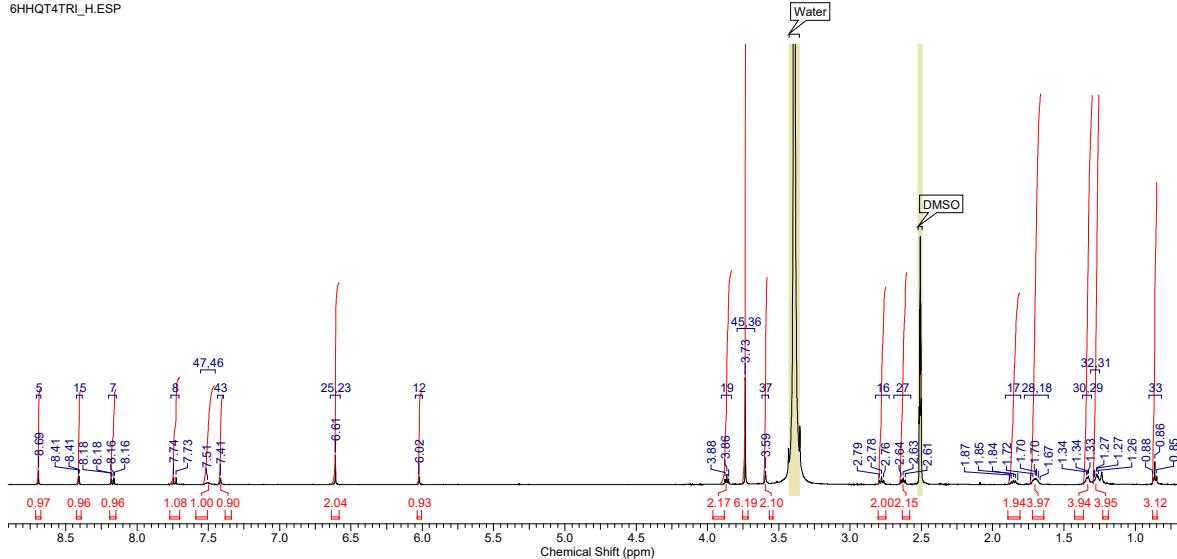


6.14 6-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1*H*-1,2,3-triazol-1-yl)-2-heptylquinolin-4(*H*)-one 95

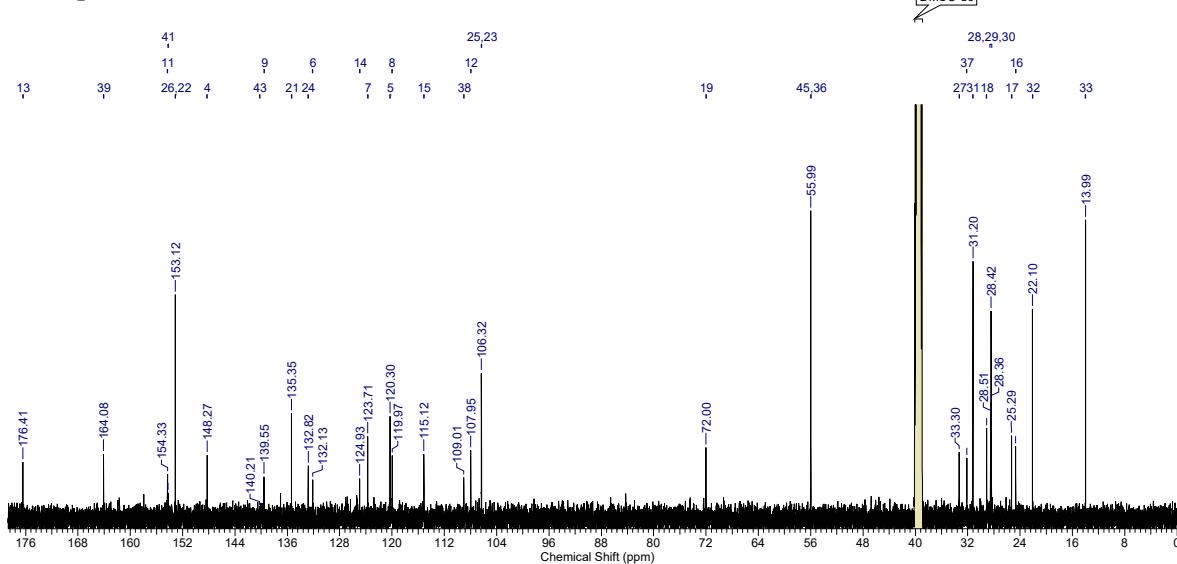
User Notes Some guesses



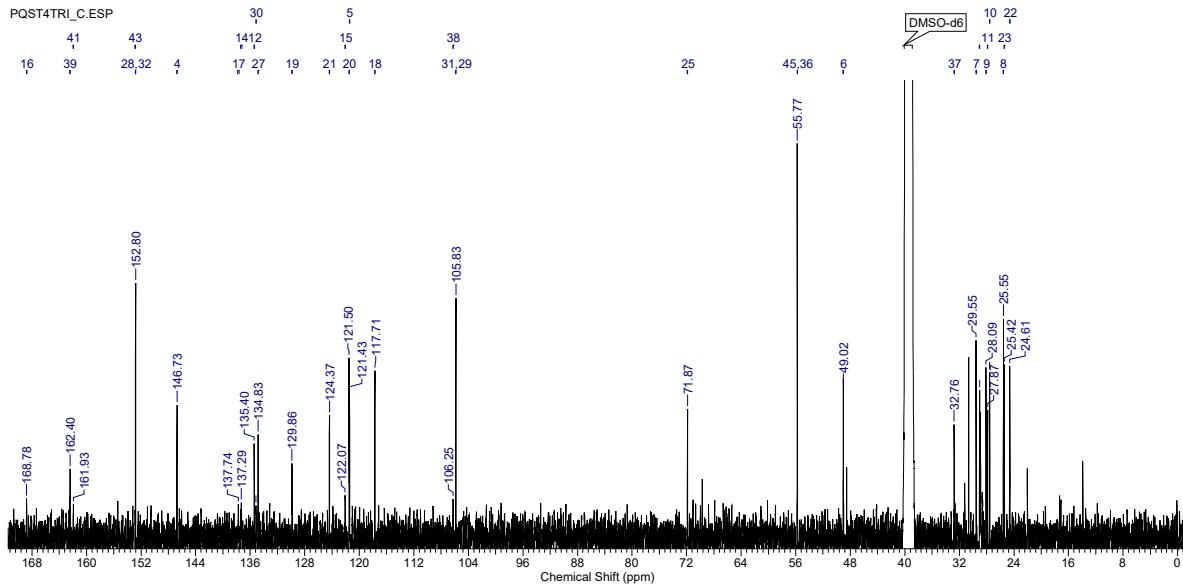
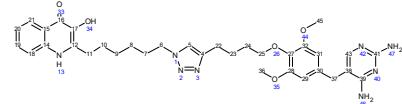
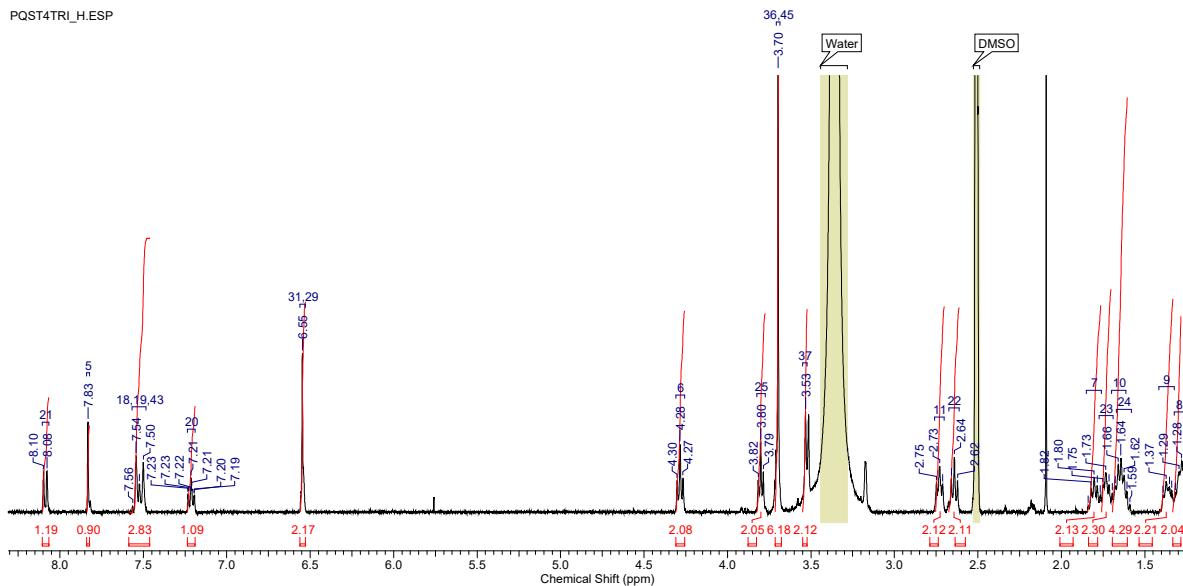
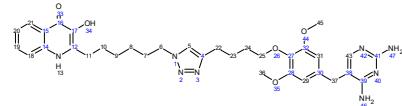
6HHQT4TRI H.ESP



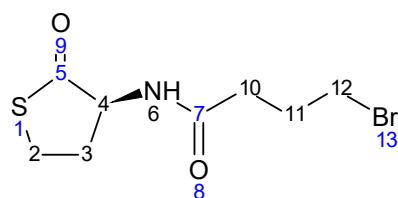
6HHQT4TRI_C.ESP



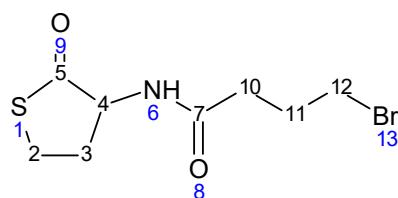
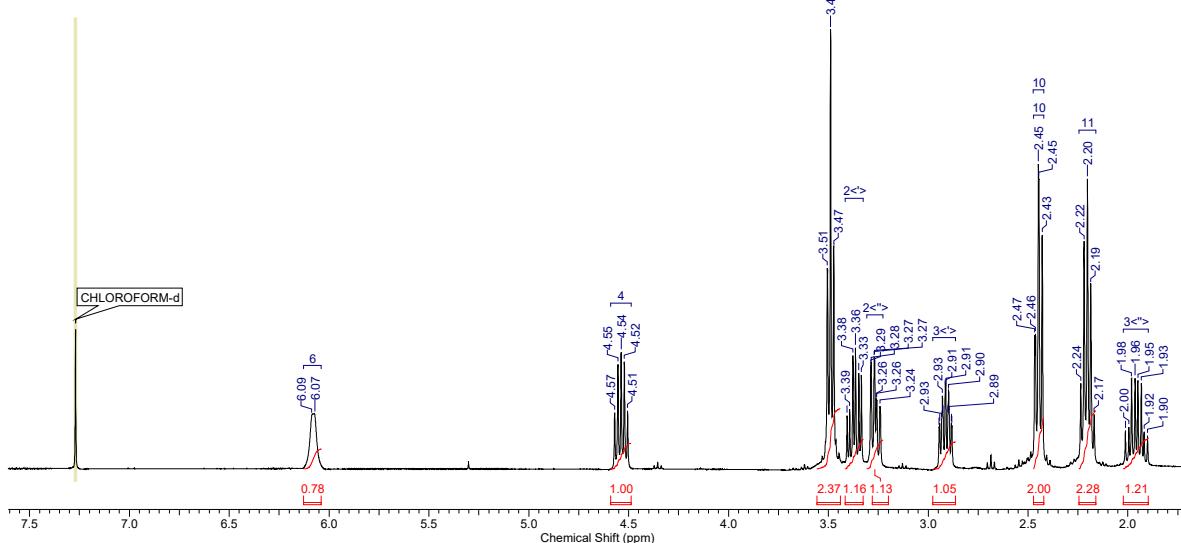
6.15 2-(6-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1*H*-1,2,3-triazol-1-yl)hexyl)-3-hydroxyquinolin-4(*H*)-one 97



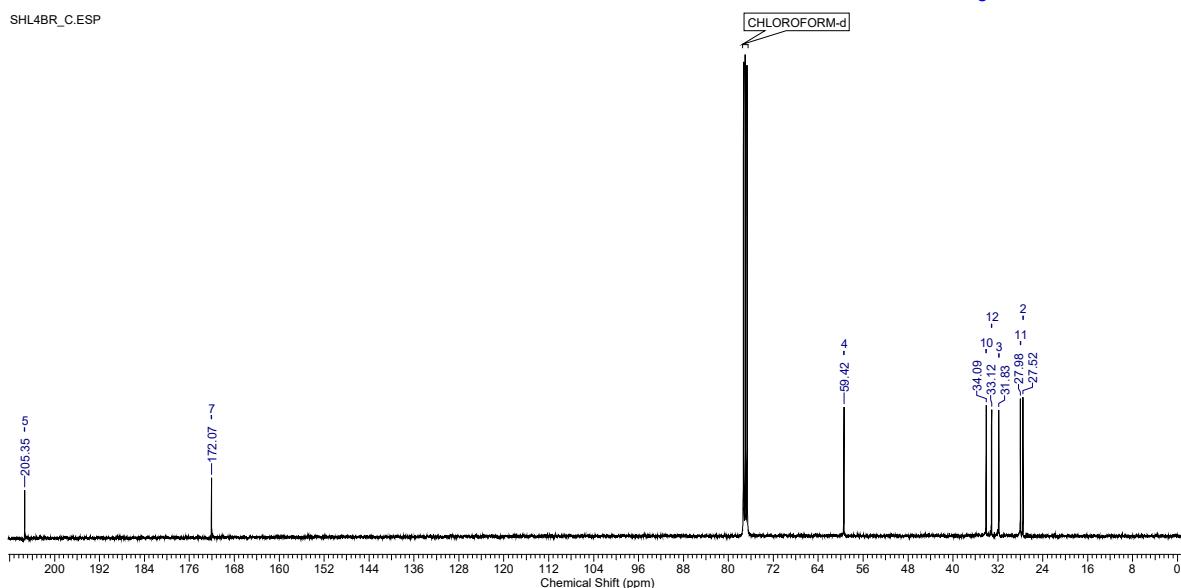
6.16 4-Bromo-*N*-(2-oxotetrahydrothiophen-3-yl)butanamide 110



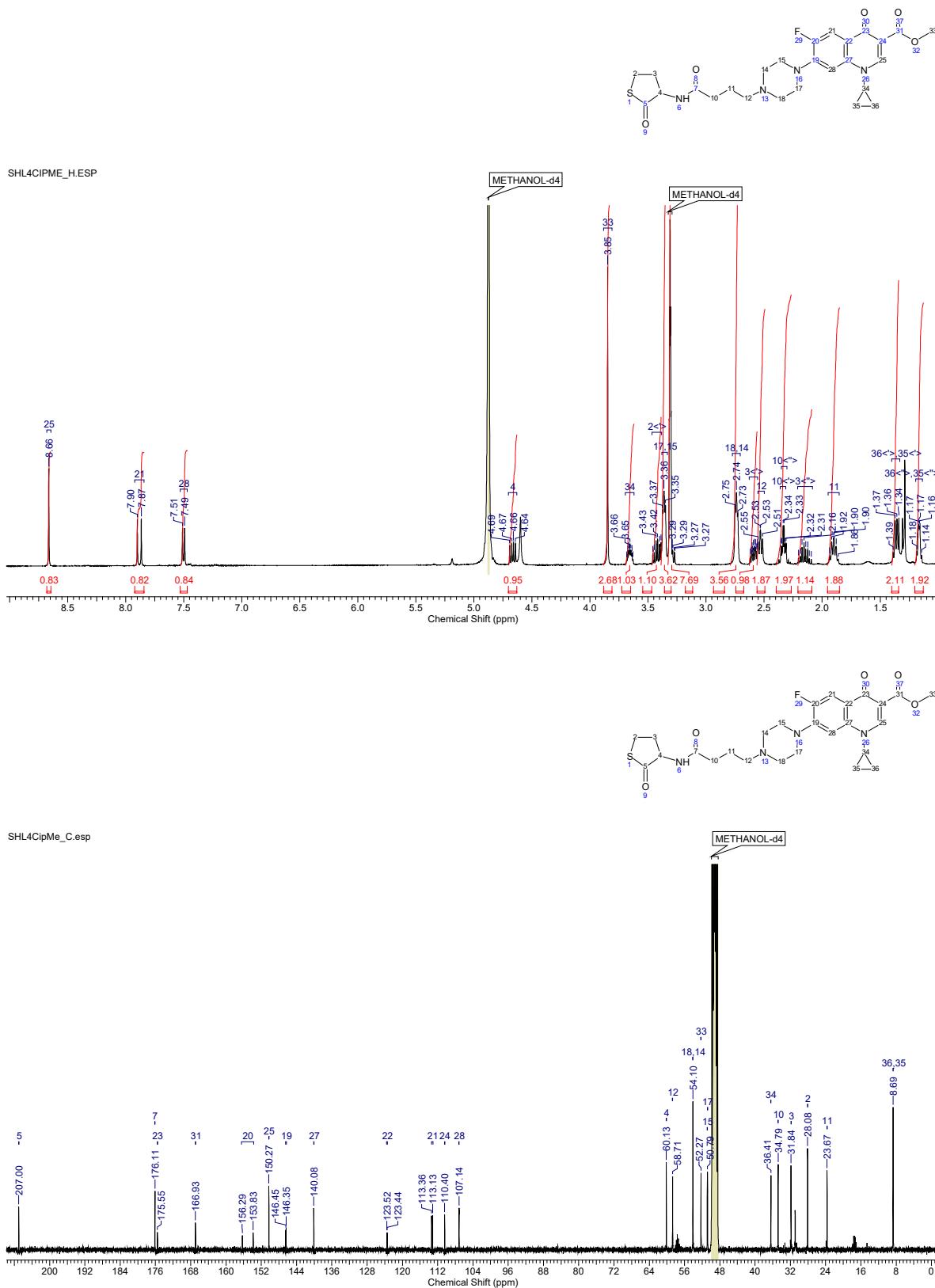
SHL4BR H.ESP



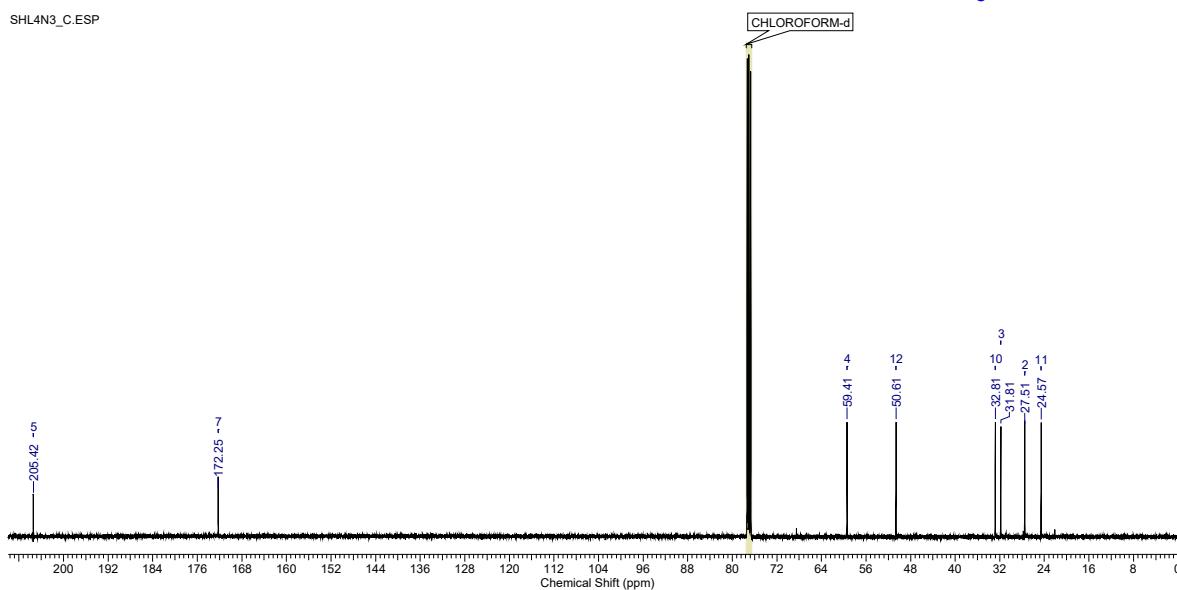
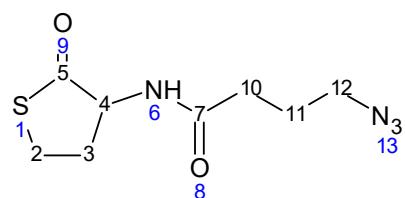
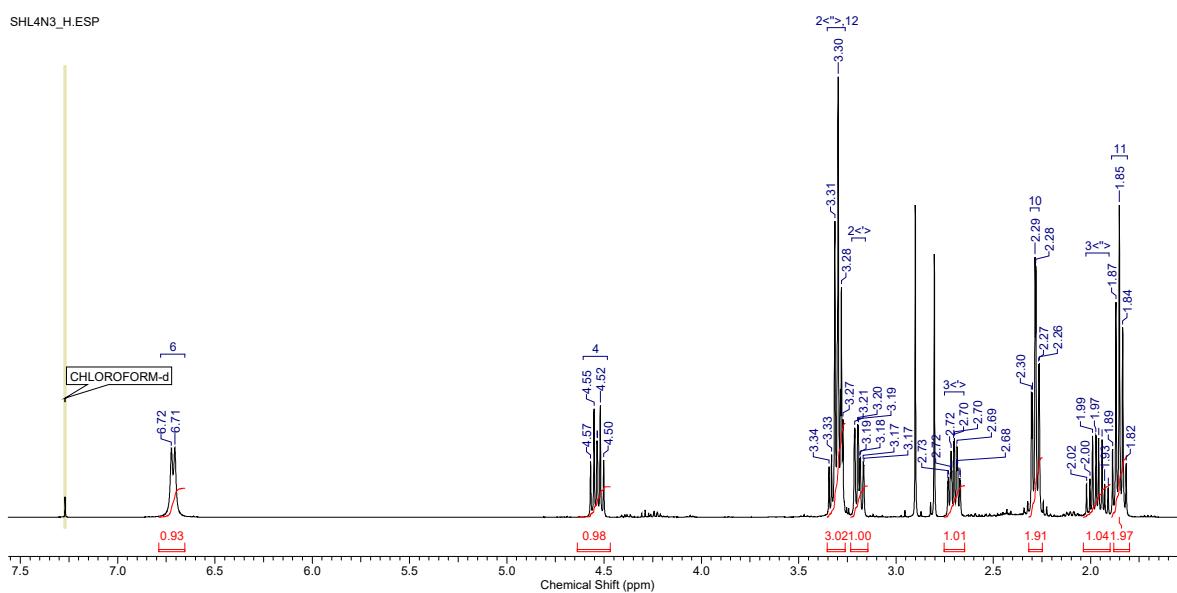
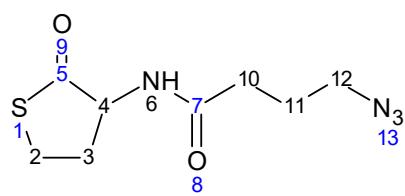
SHL4BR C.ESP



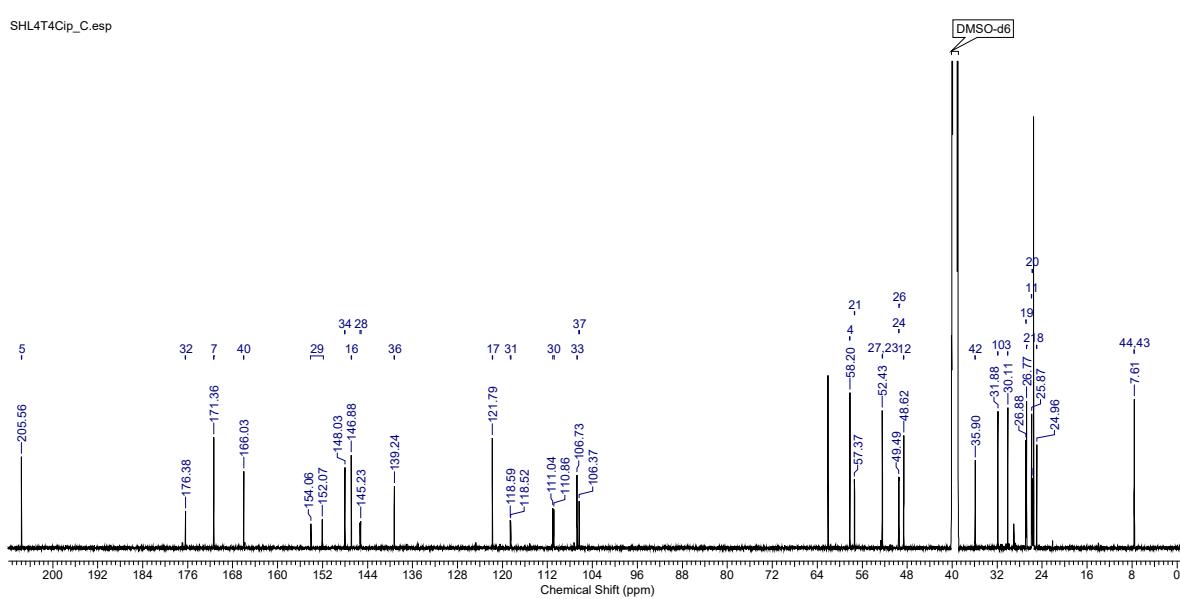
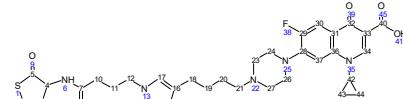
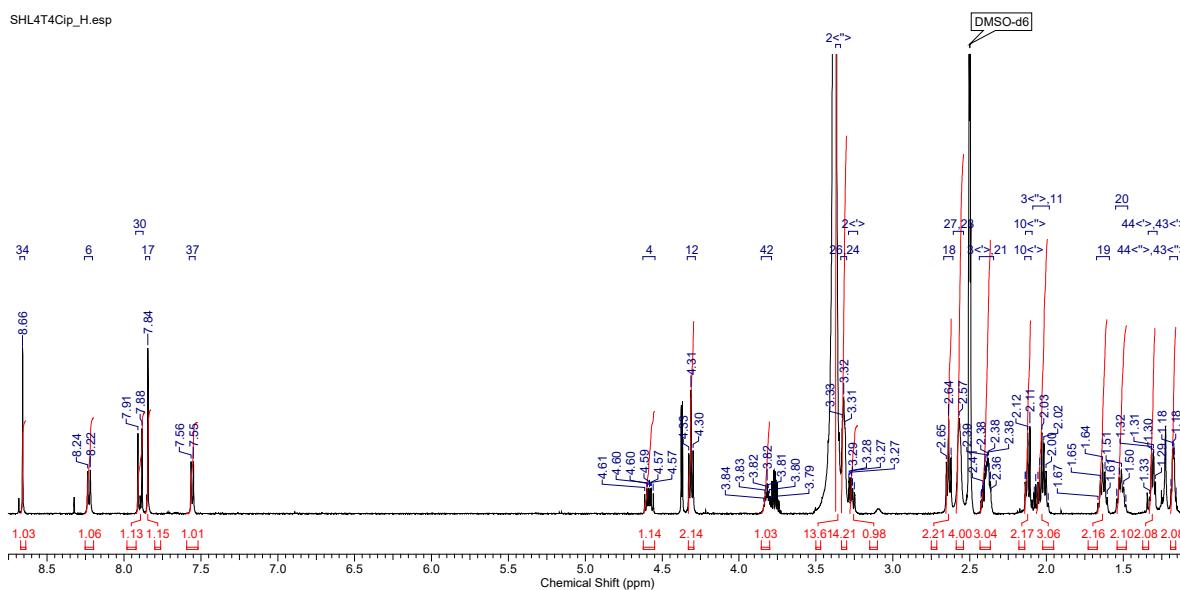
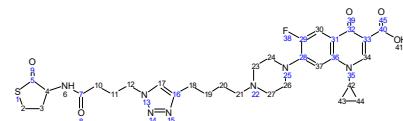
6.17 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 111



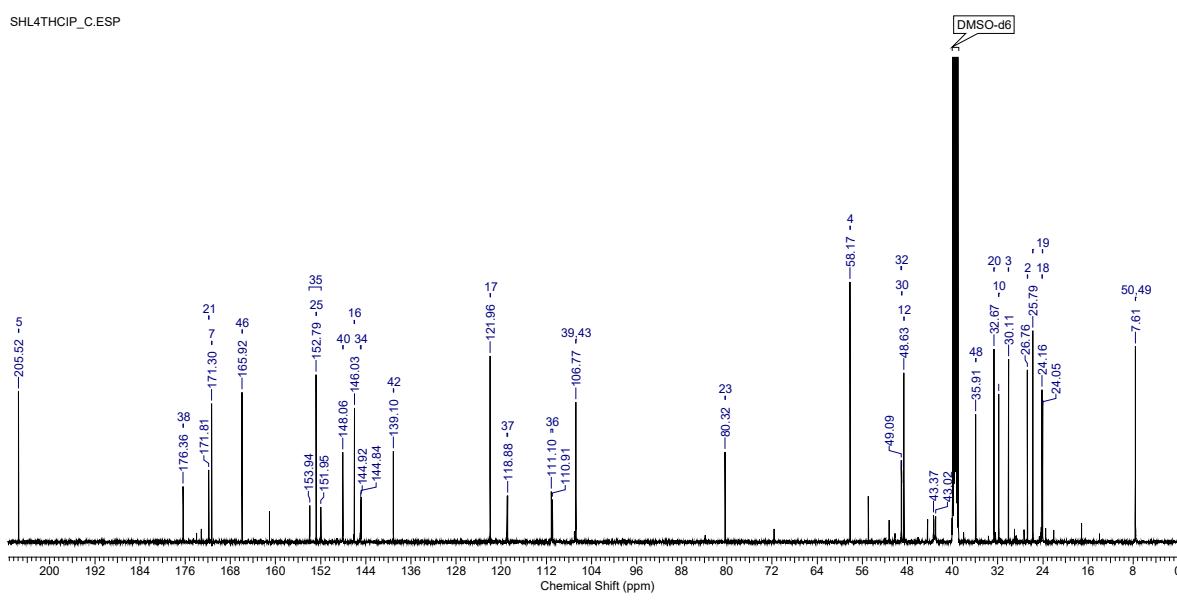
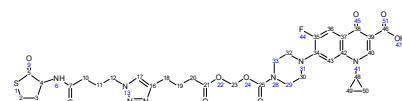
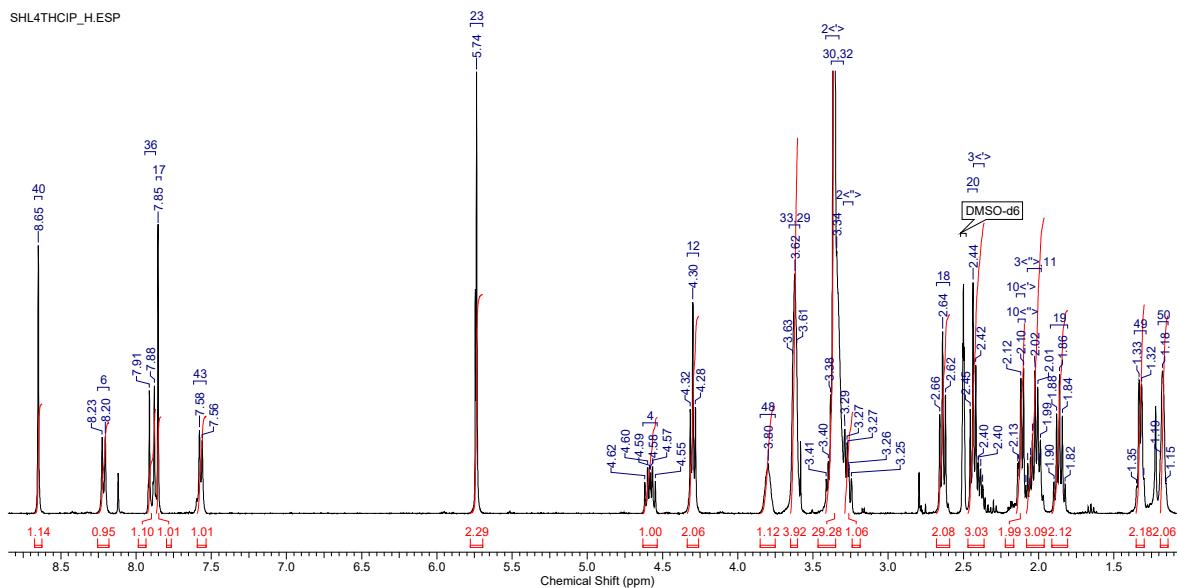
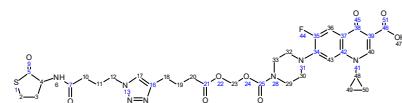
6.18 4-Azido-*N*-(2-oxotetrahydrothiophen-3-yl)butanamide 112



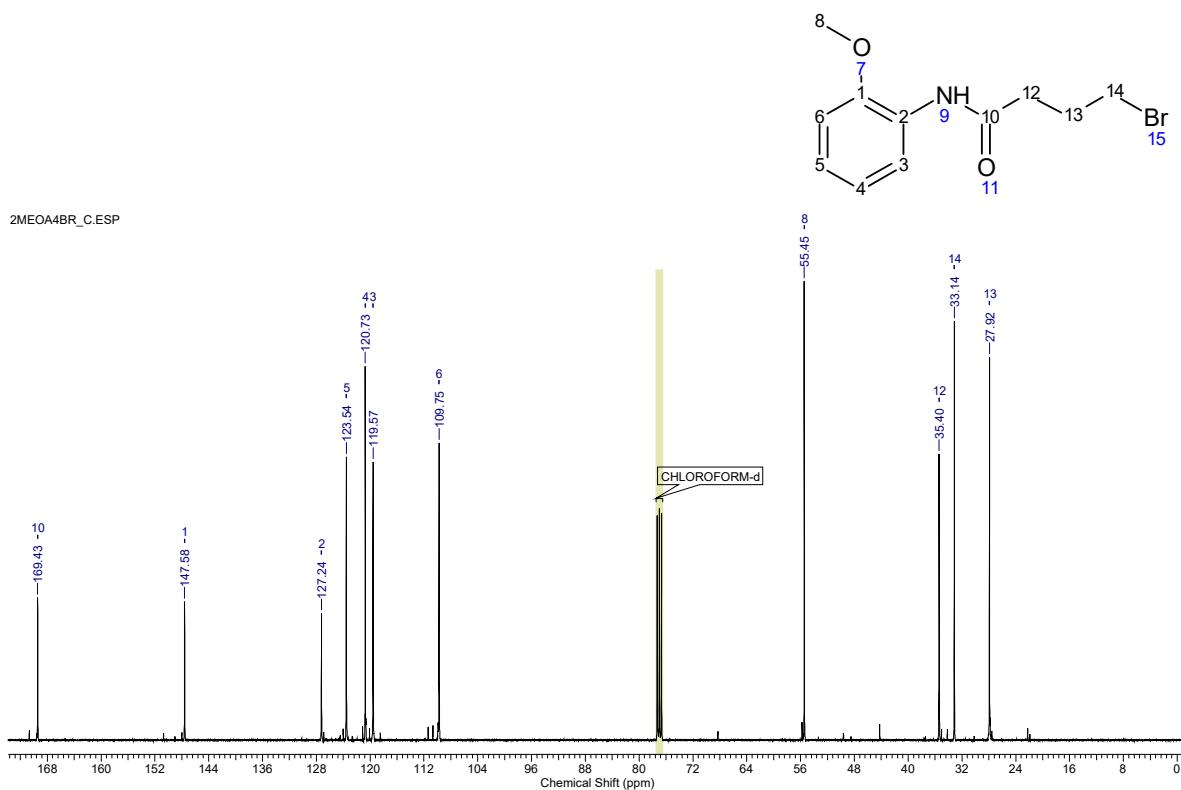
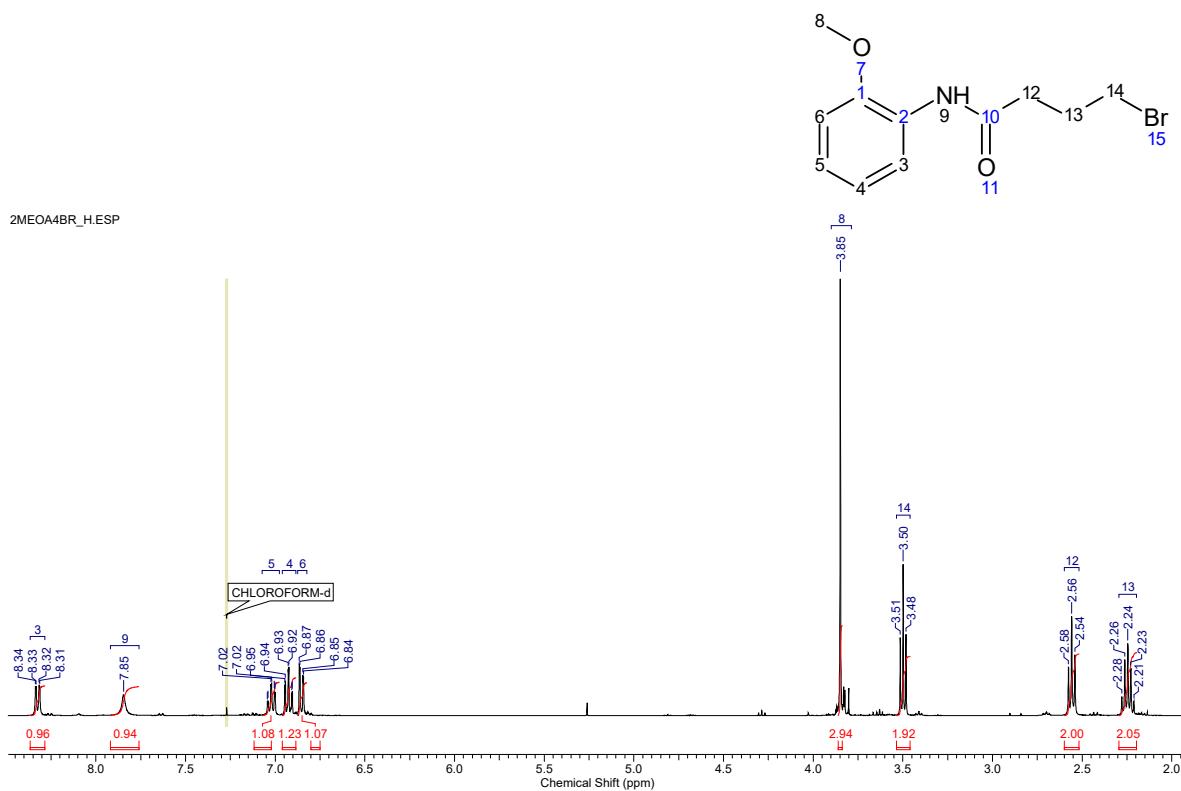
6.19 1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(1-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 113



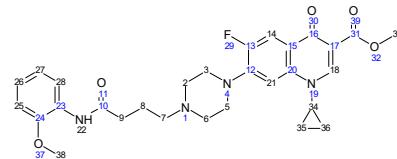
6.20 1-Cyclopropyl-6-fluoro-4-oxo-7-(((4-(1-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)-1*H*-1,2,3-triazol-4-yl)butanoyl)oxy)methoxy)carbonyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 114



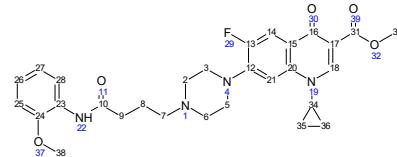
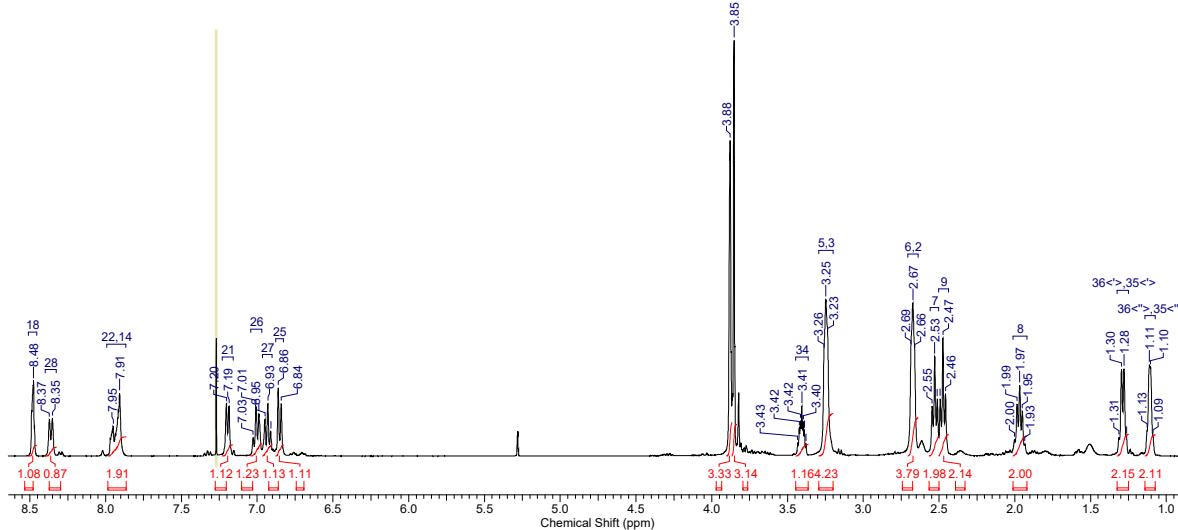
6.21 4-Bromo-N-(2-methoxyphenyl)butanamide 116



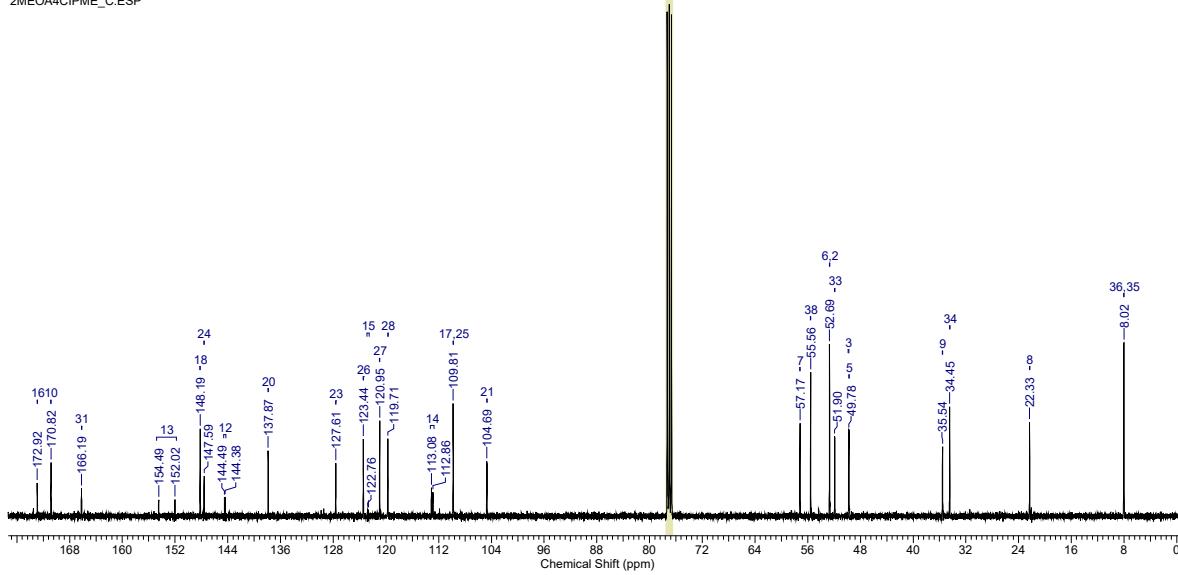
6.22 Methyl 1-cyclopropyl-6-fluoro-7-(4-((2-methoxyphenyl)amino)-4-oxobutyl)-piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 117



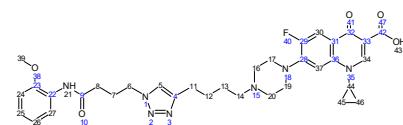
2MEOA4CIPME_H.ESP



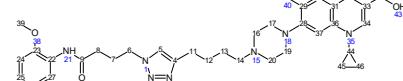
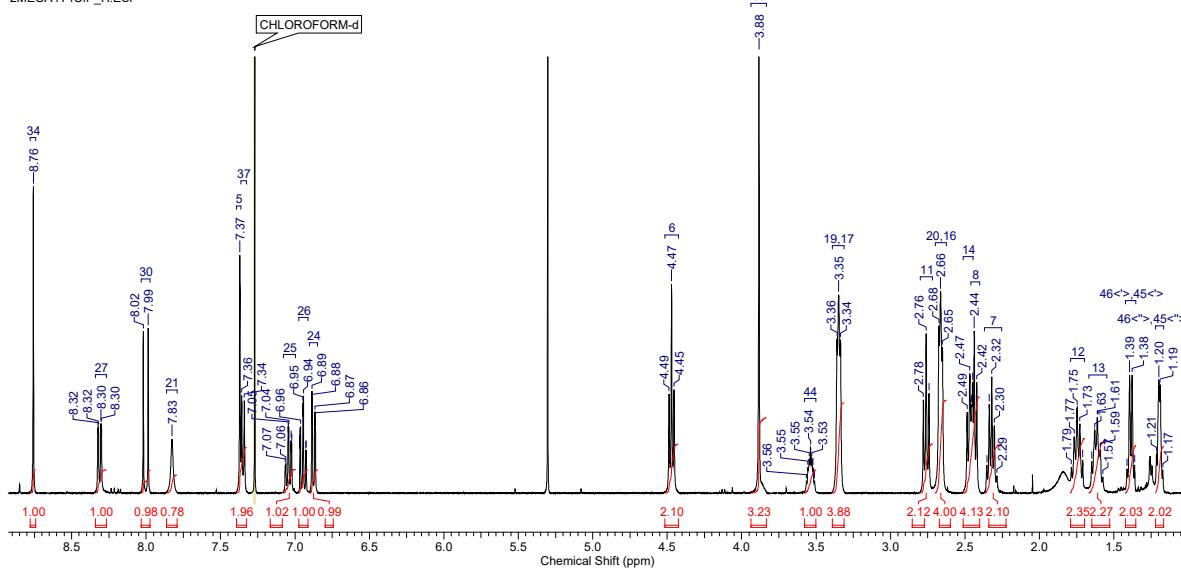
2MEOA4CIPME_C.ESP



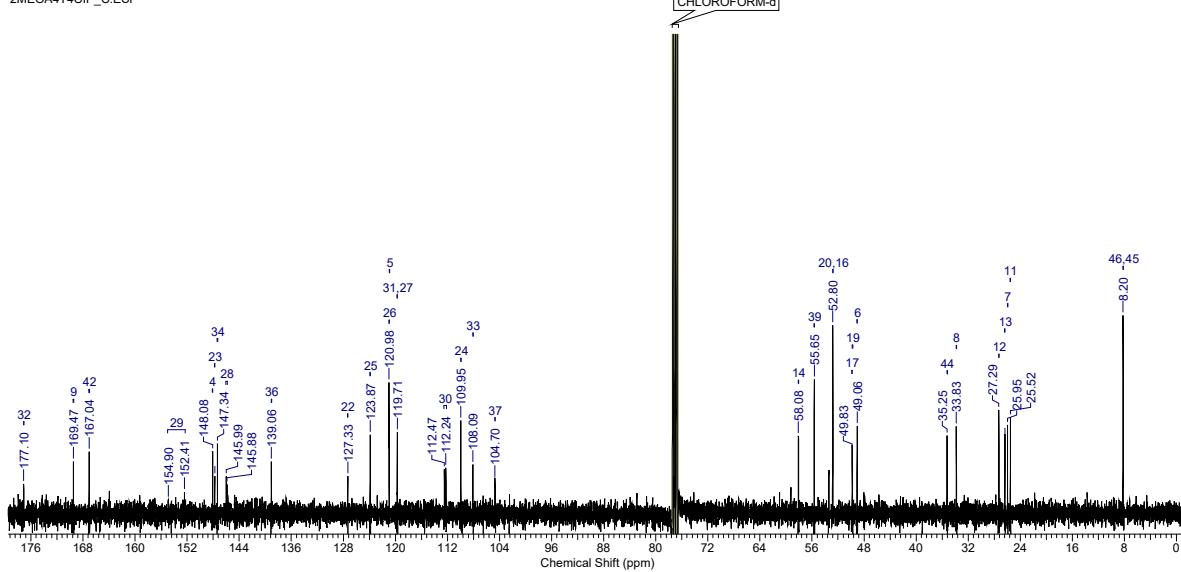
6.23 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((2-methoxyphenyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl) piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 119



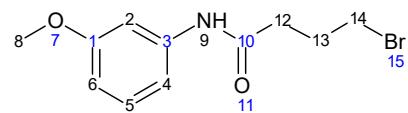
2MEOA4T4CIP_H_ESP



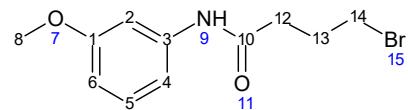
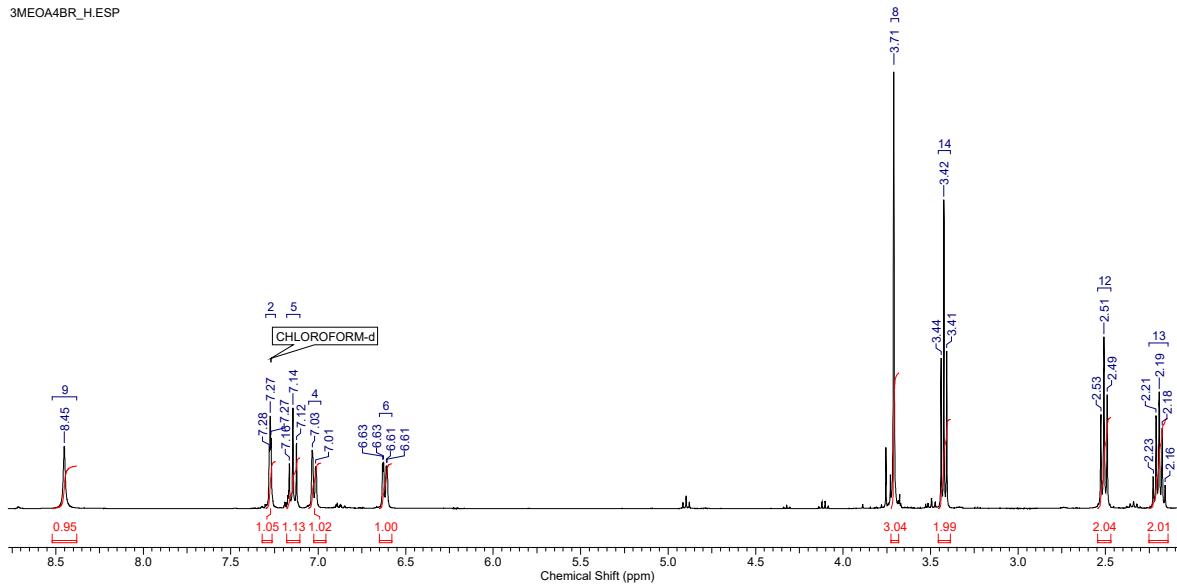
2MEOA4T4CIP_C_ESP



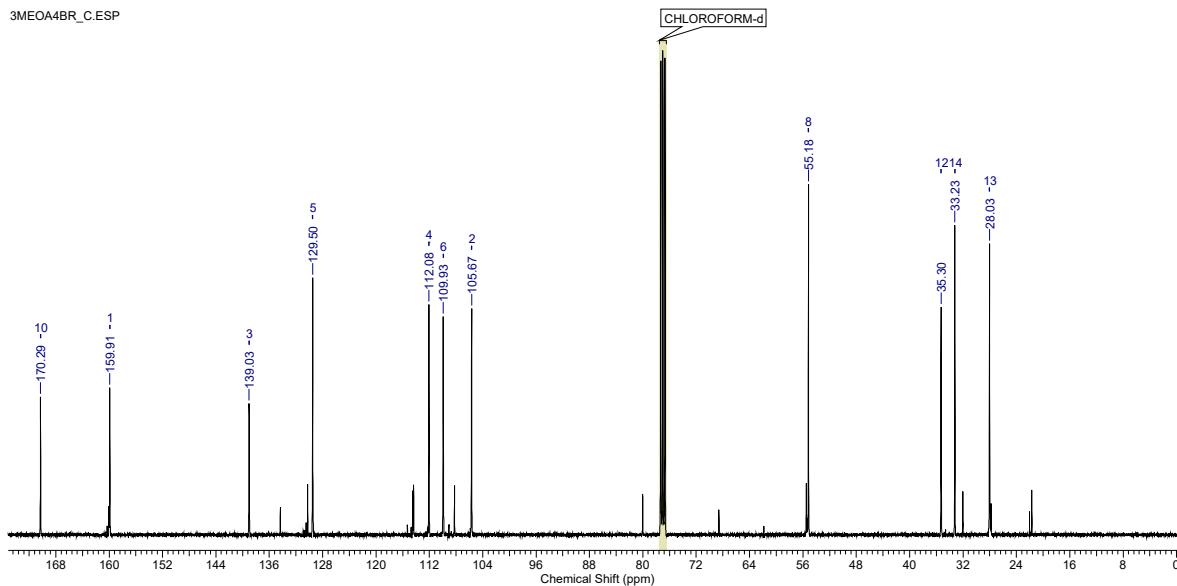
6.24 4-Bromo-N-(3-methoxyphenyl)butanamide 121



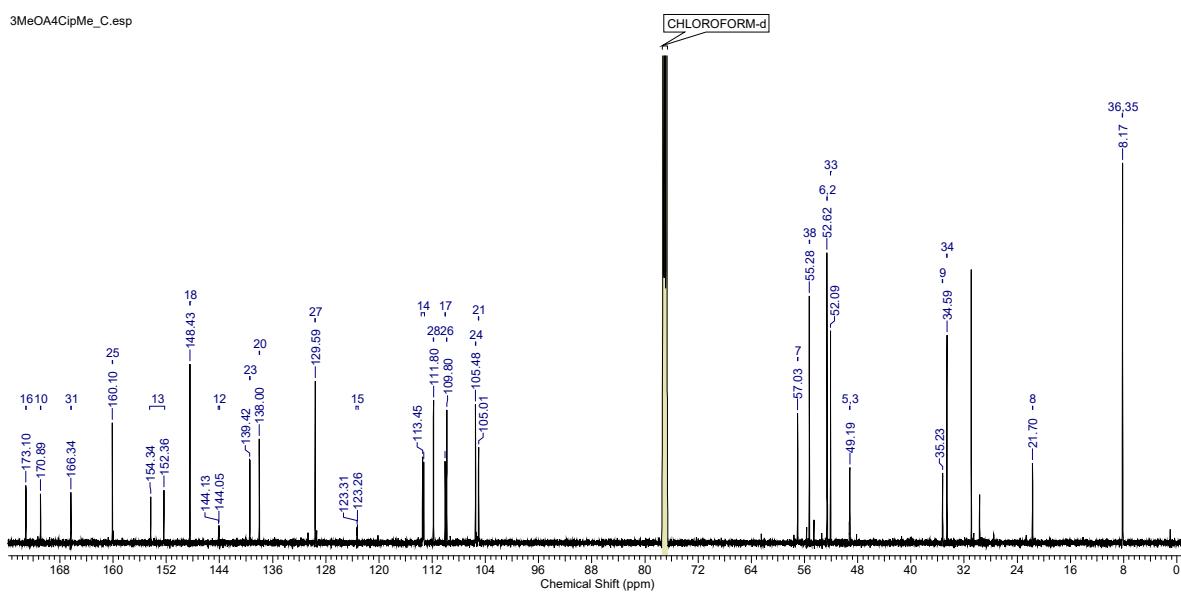
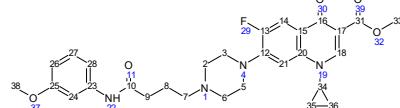
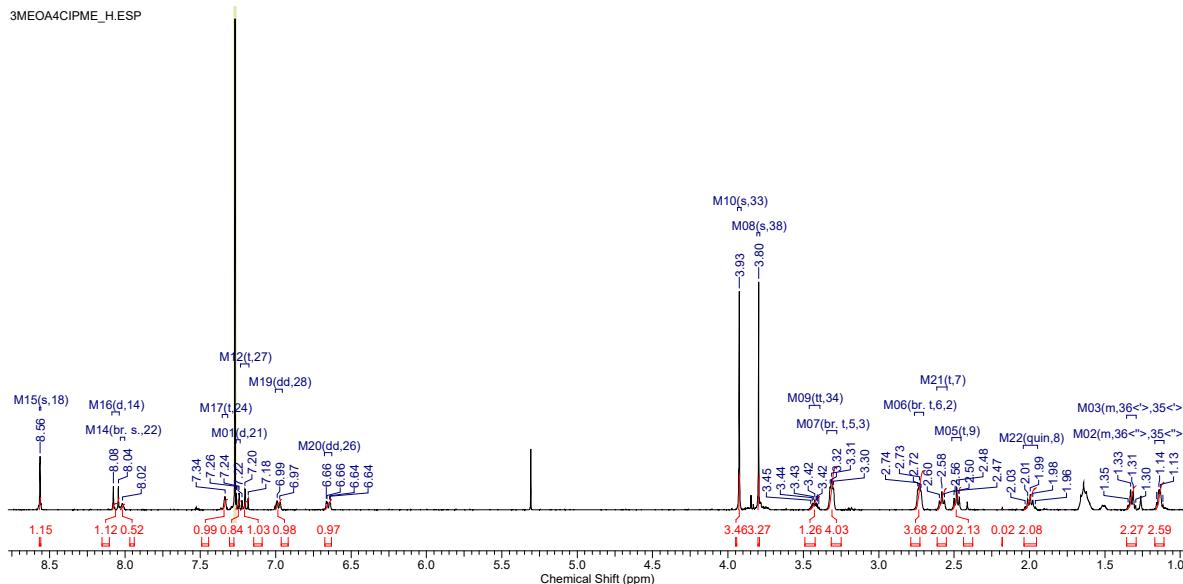
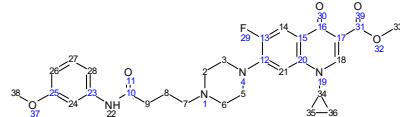
3MEOA4BR_H.ESP



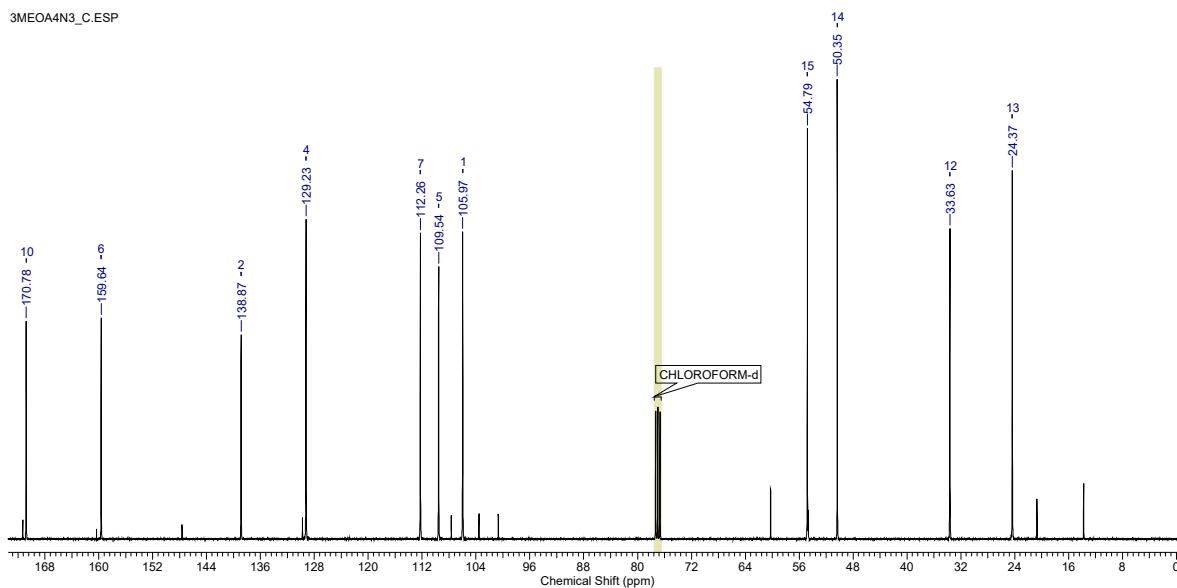
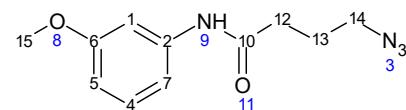
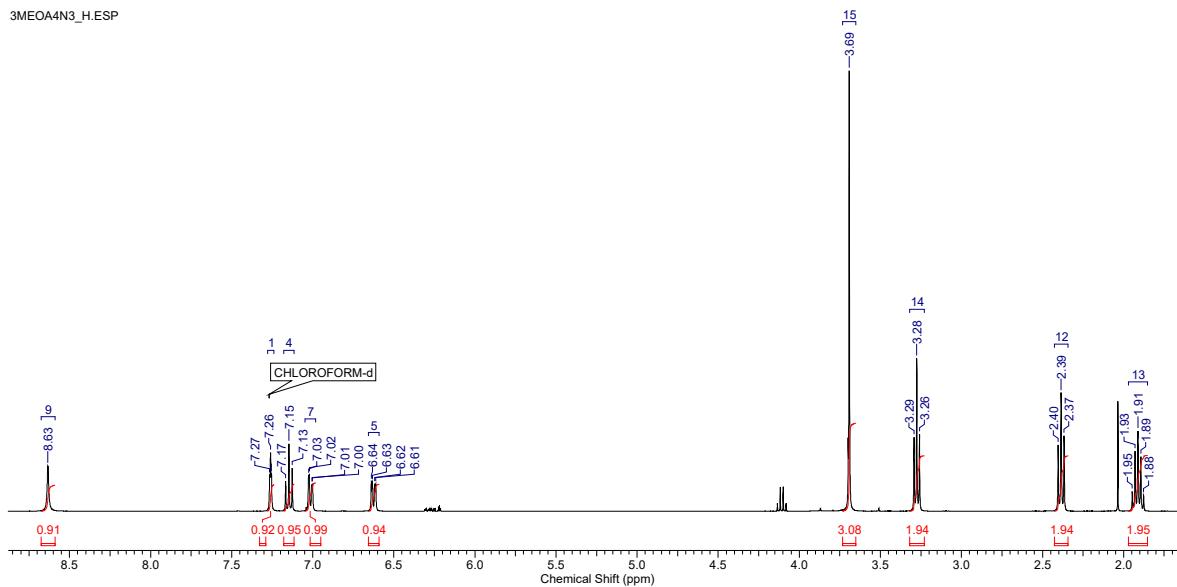
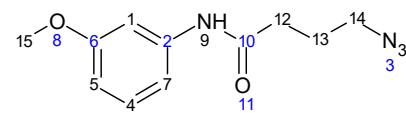
3MEOA4BR_C.ESP



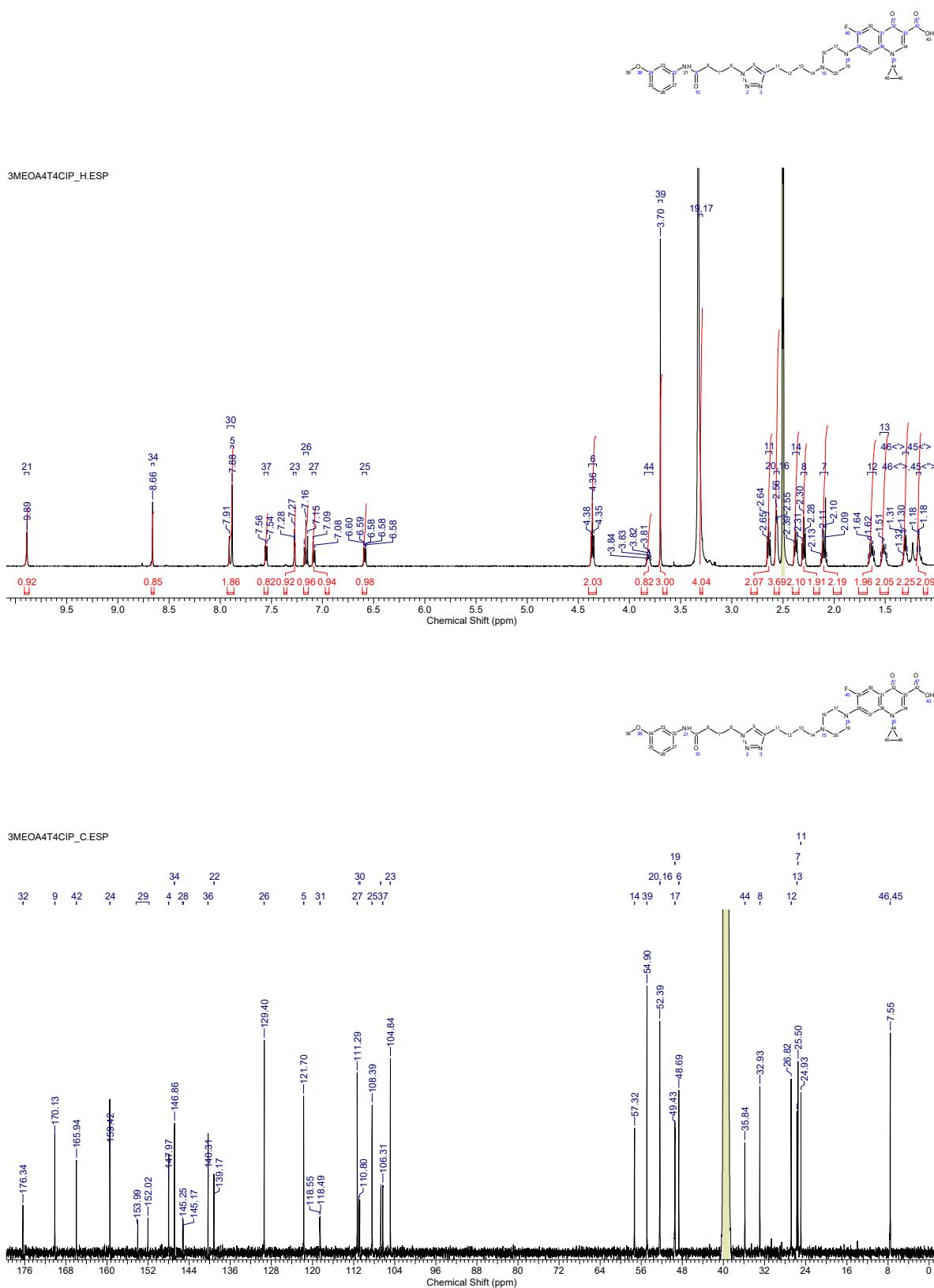
6.25 Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-((3-methoxyphenyl)amino)-4-oxobutyl)-piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 122



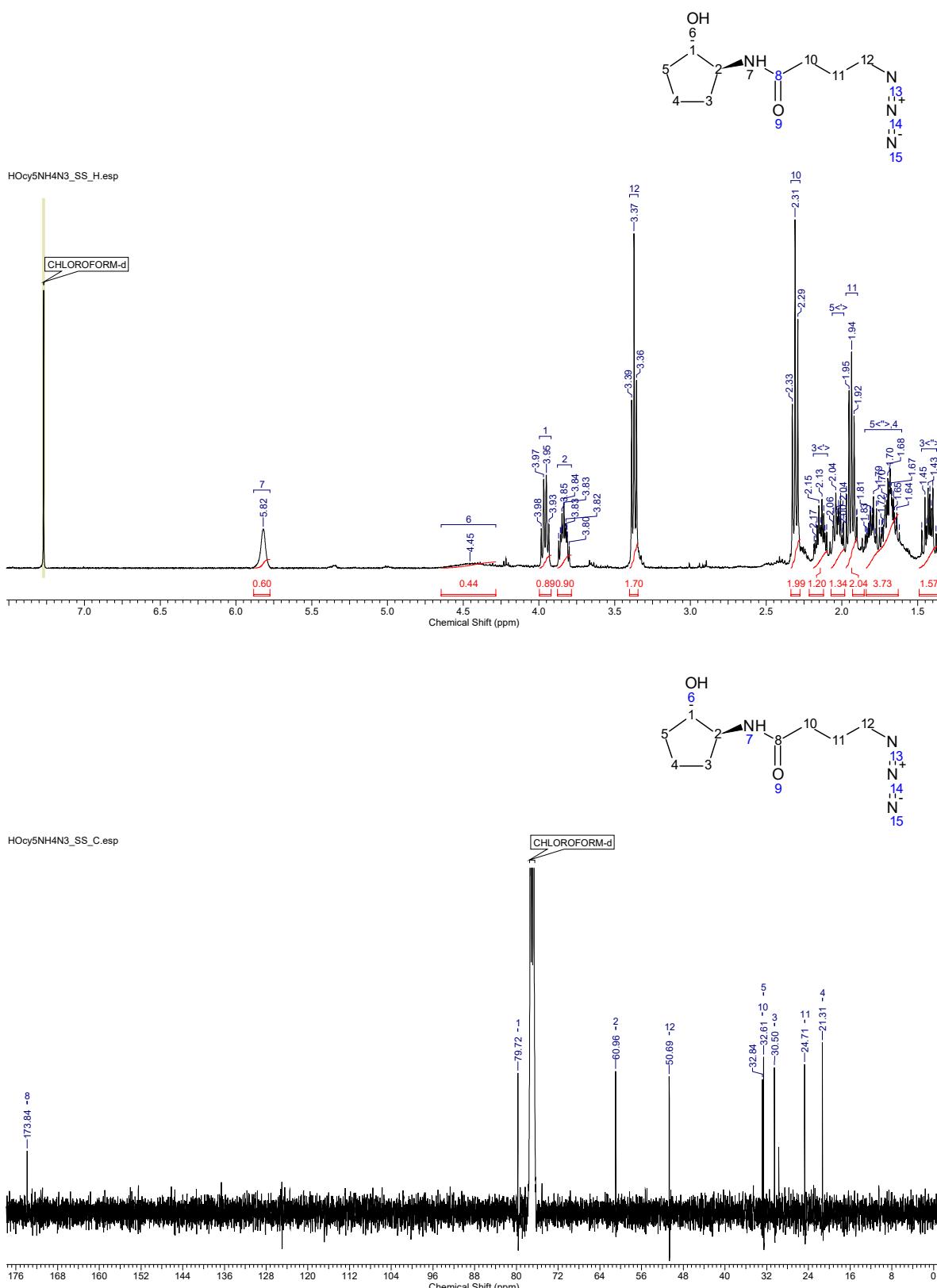
6.26 4-Azido-*N*-(3-methoxyphenyl)butanamide 123



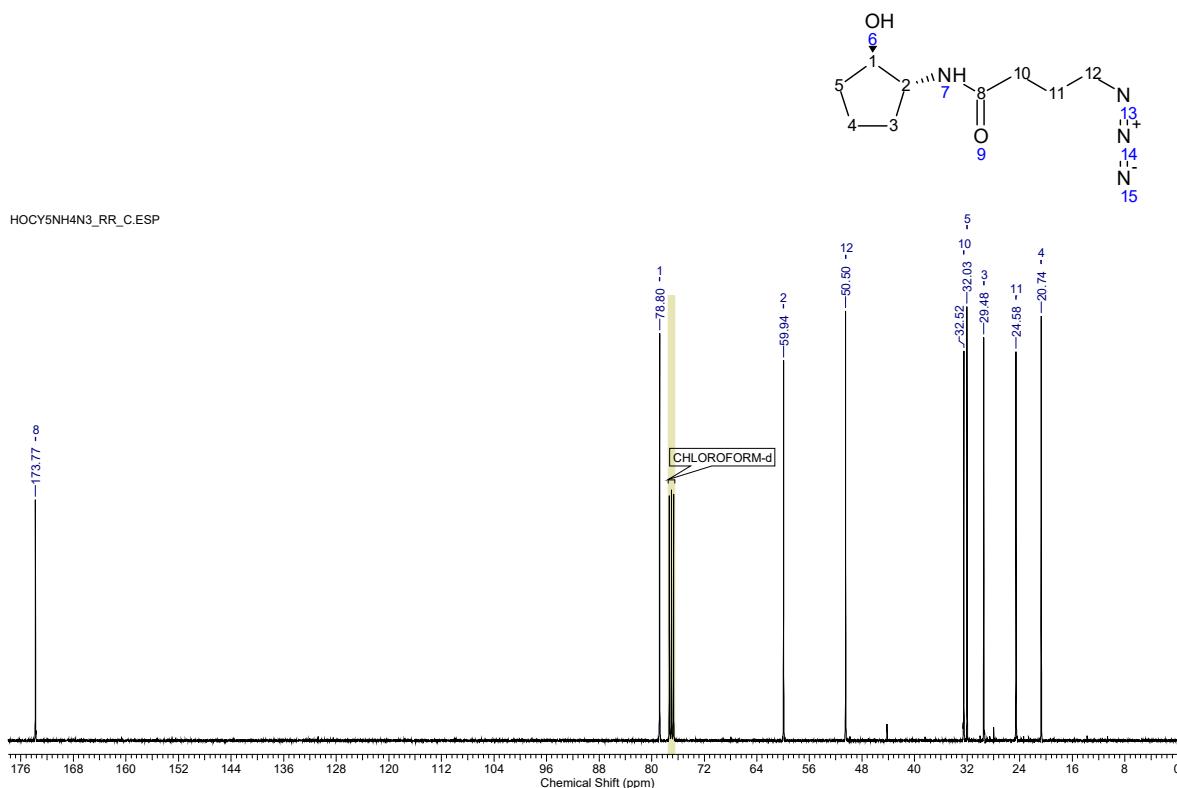
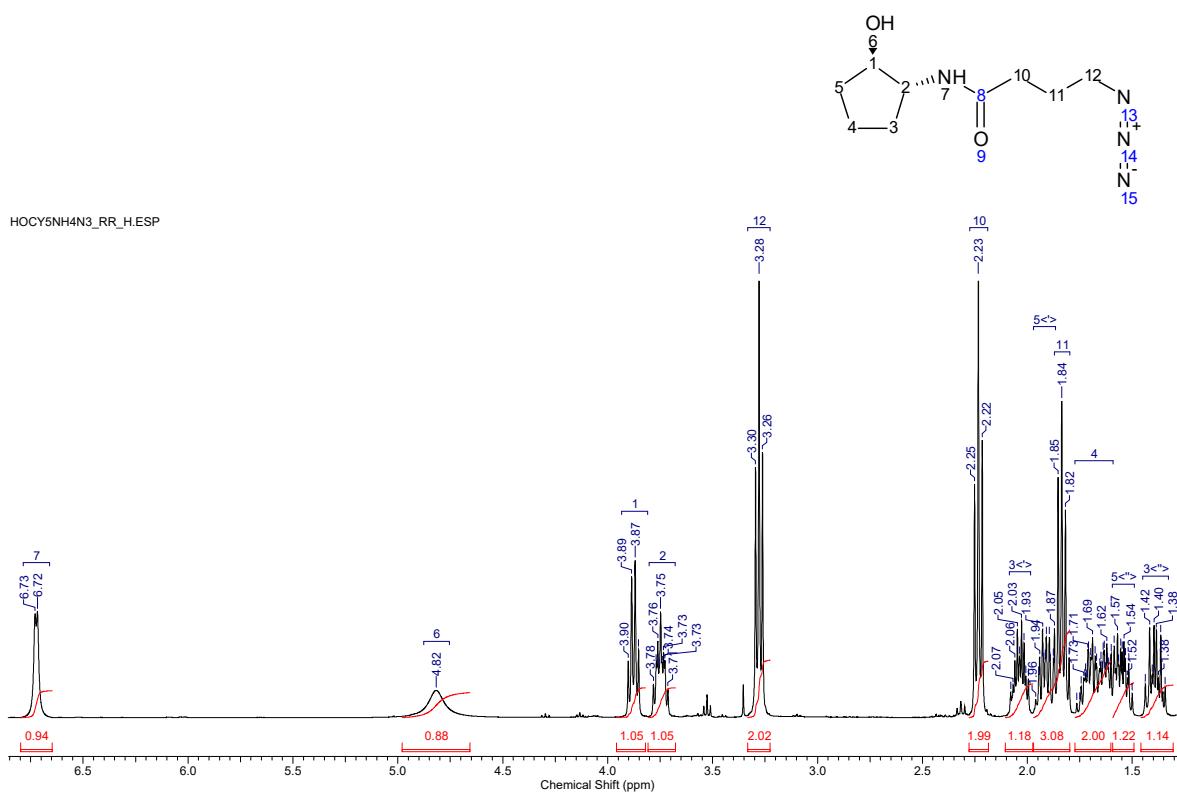
6.27 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((3-methoxyphenyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 124



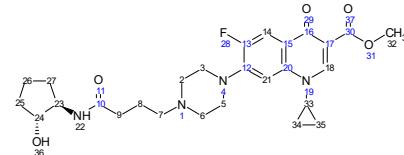
6.28 4-Azido-*N*-(*(1S,2S)*-2-hydroxycyclopentyl)butanamide 133



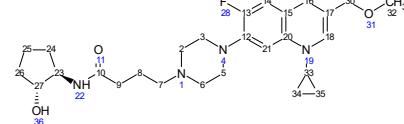
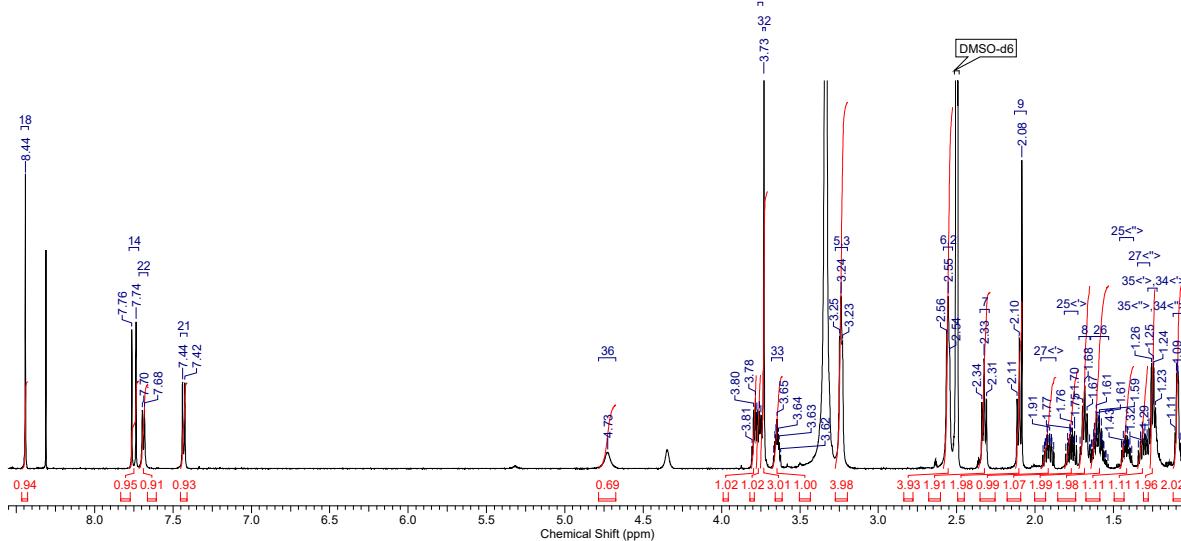
6.29 4-Azido-*N*-(*(1R,2R)*-2-hydroxycyclopentyl)butanamide 134



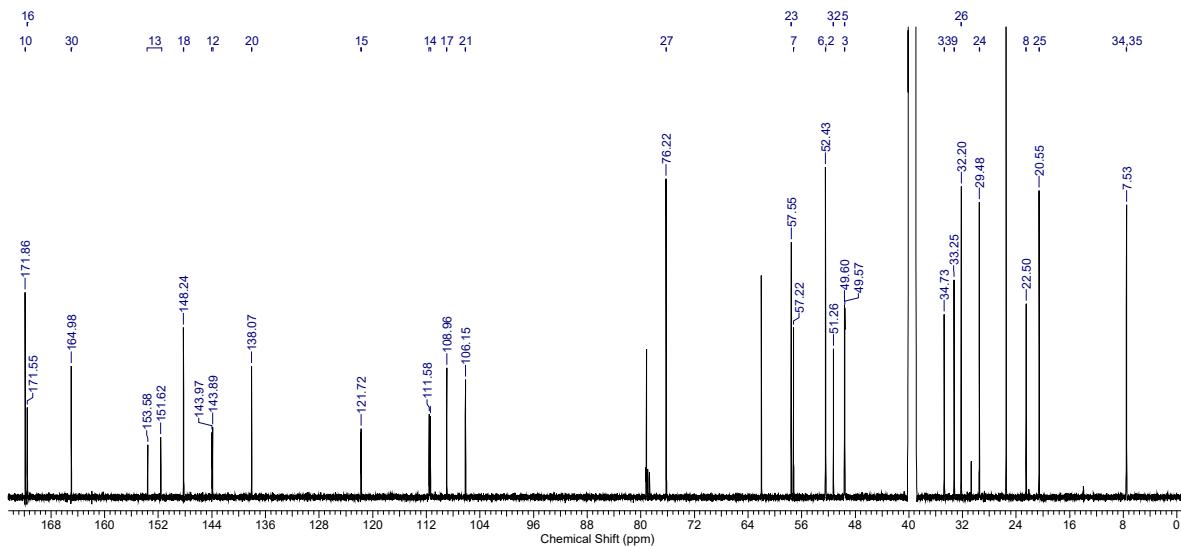
6.30 Methyl 1-cyclopropyl-6-fluoro-7-(4-((1*S*,2*S*)-2-hydroxycyclopentyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 135



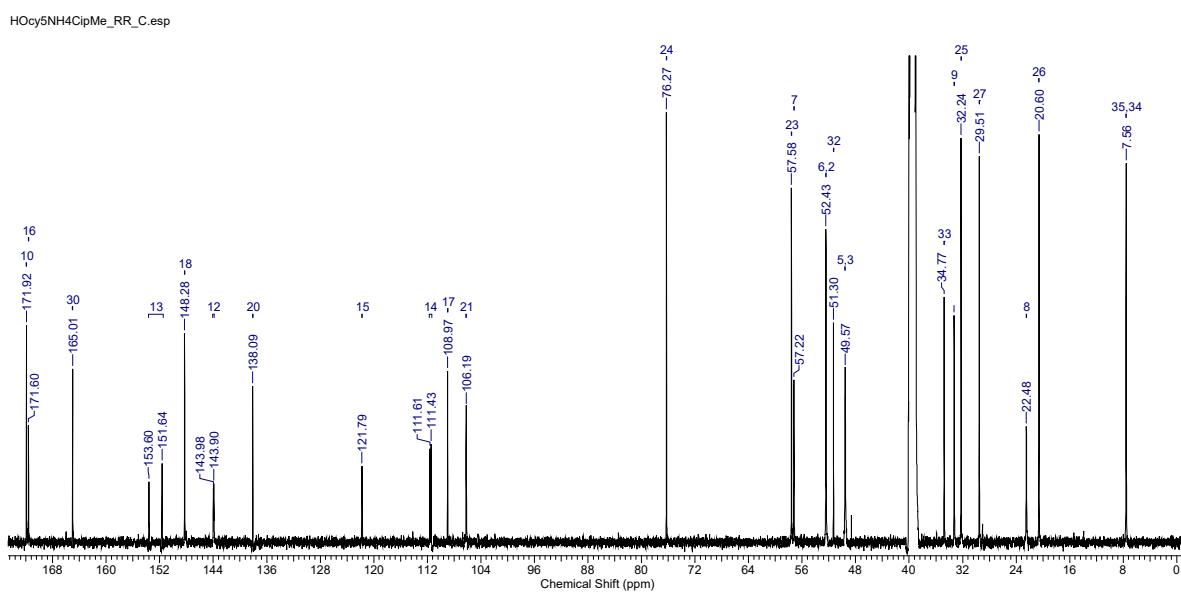
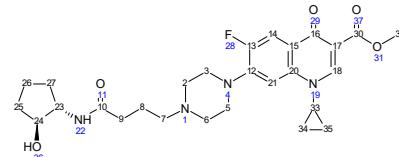
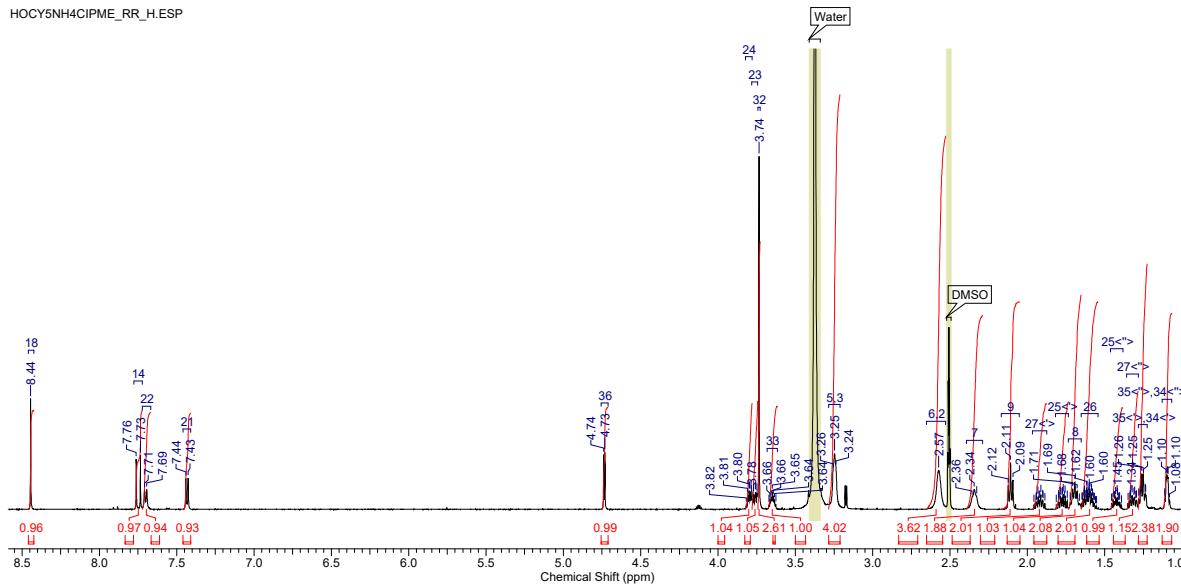
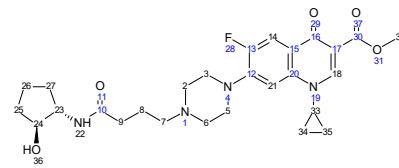
HOcy5NH4CipMe_SS_H.esp



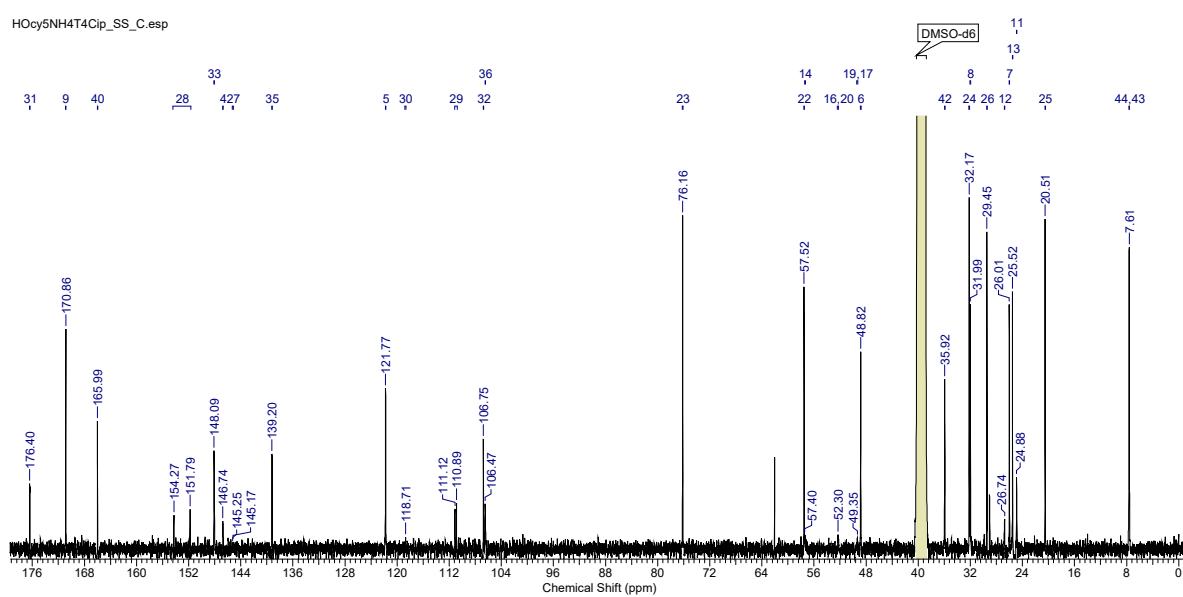
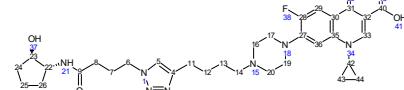
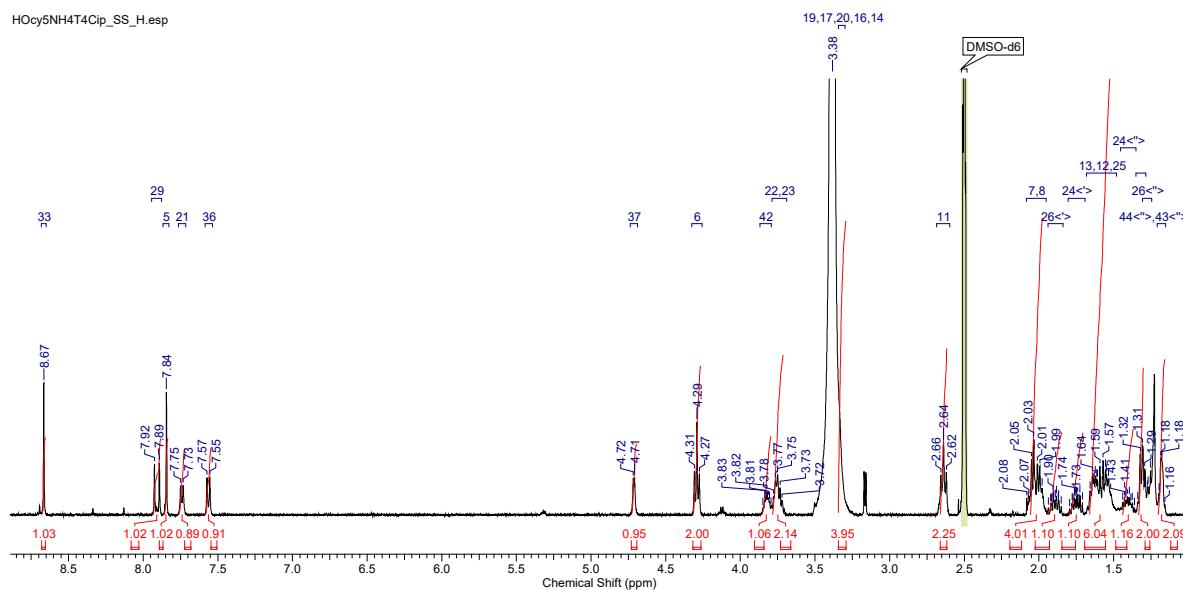
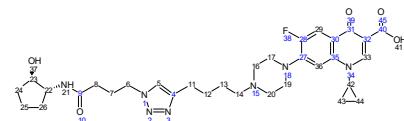
HOcy5NH4CipMe_SS_C.esp



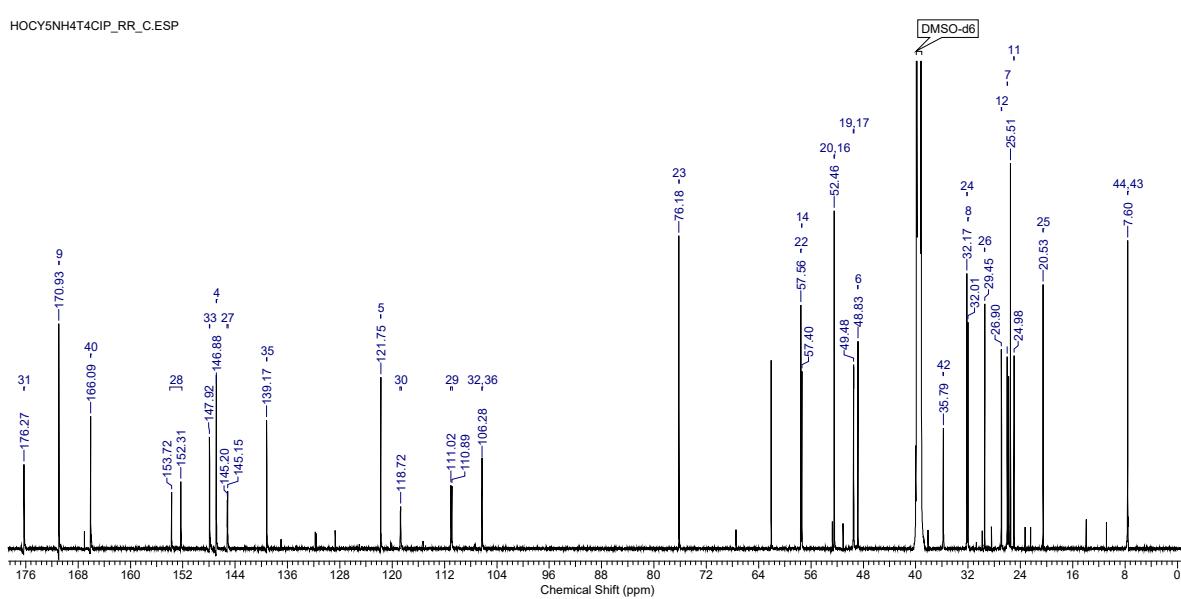
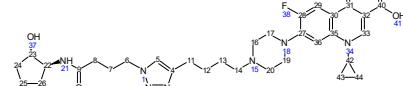
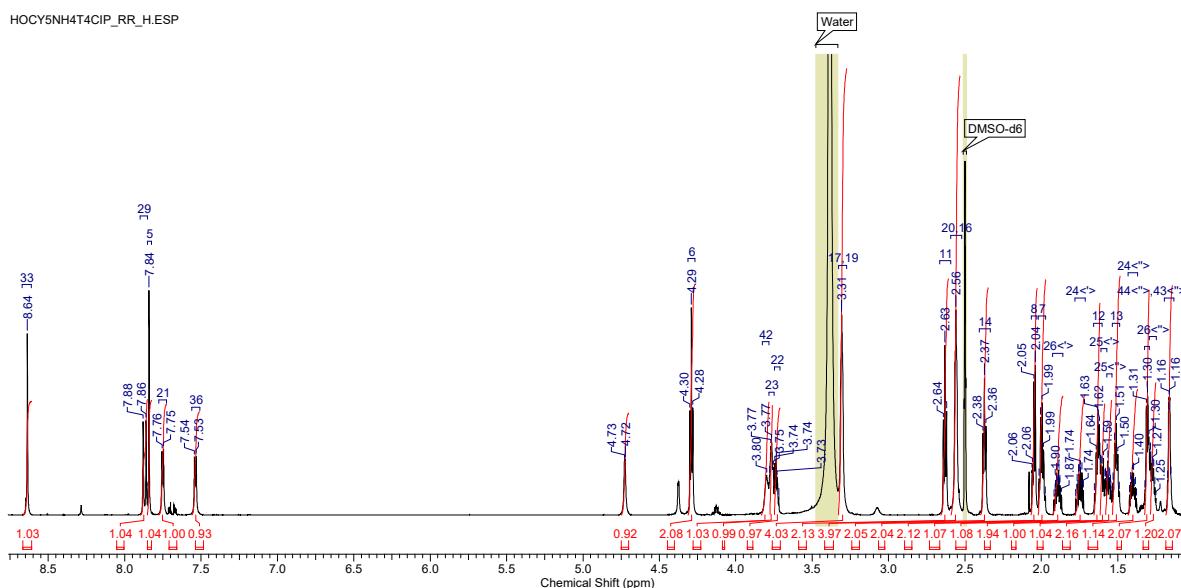
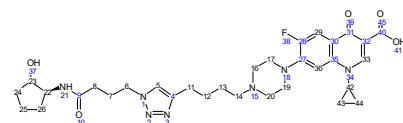
6.31 Methyl 1-cyclopropyl-6-fluoro-7-(4-((1*R*,2*R*)-2-hydroxycyclopentyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 136



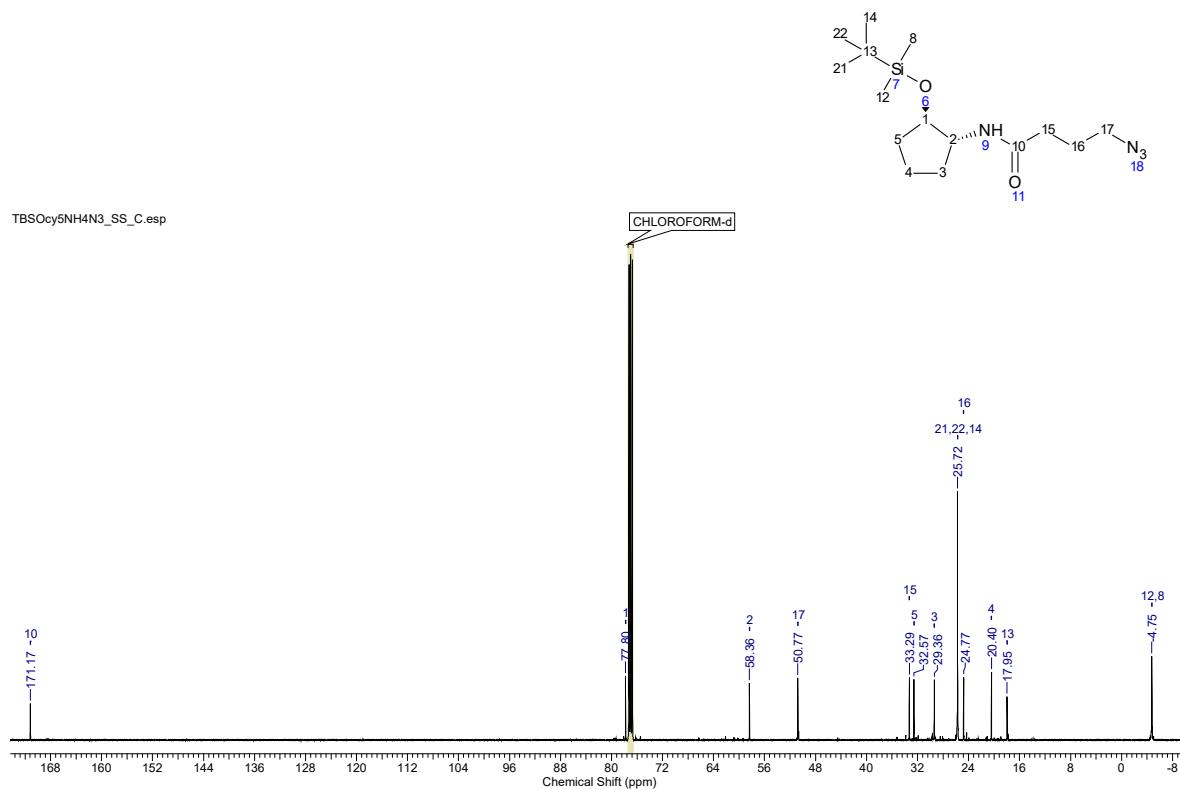
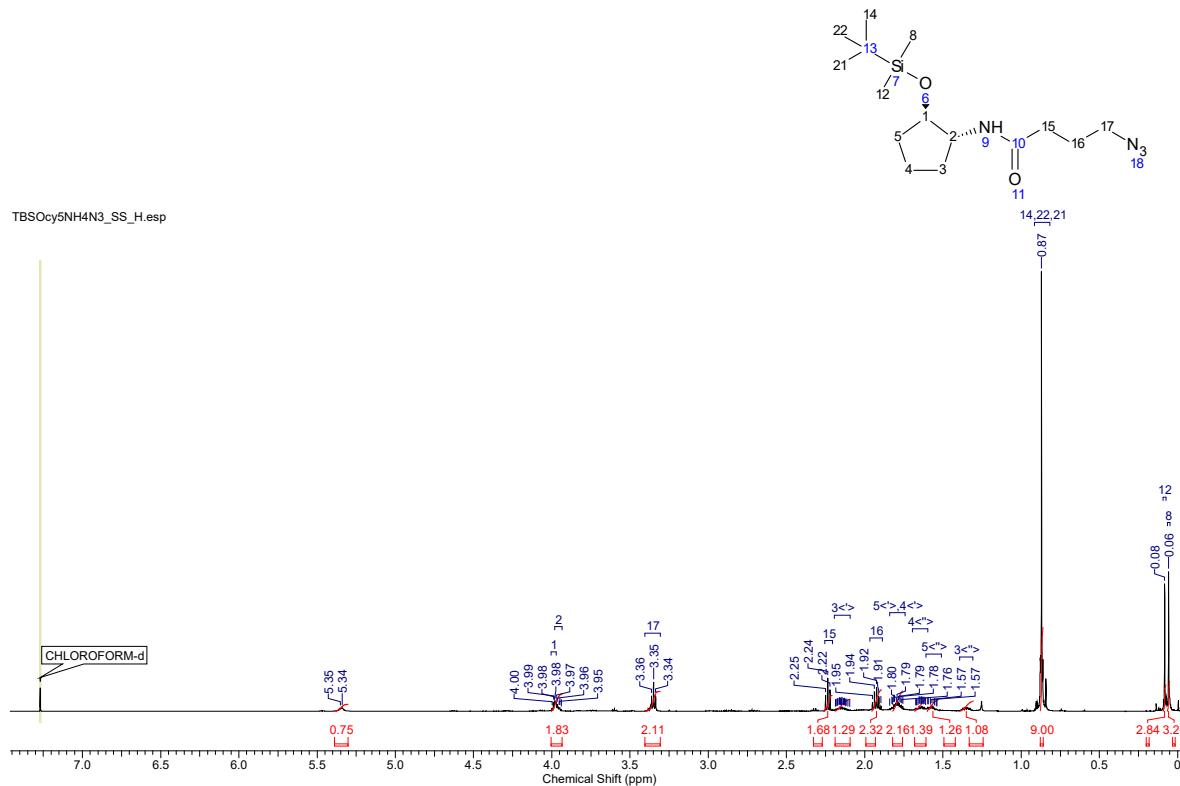
6.32 1-Cyclopropyl-6-fluoro-7-(4-(1-(4-(((1*S*,2*S*)-2-hydroxycyclopentyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquino-line-3-carboxylic acid 138



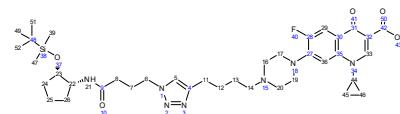
6.33 1-Cyclopropyl-6-fluoro-7-(4-(1-(4-(((1*R*,2*R*)-2-hydroxycyclopentyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquino-line-3-carboxylic acid 139



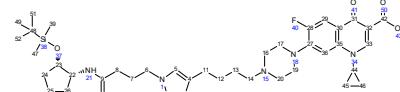
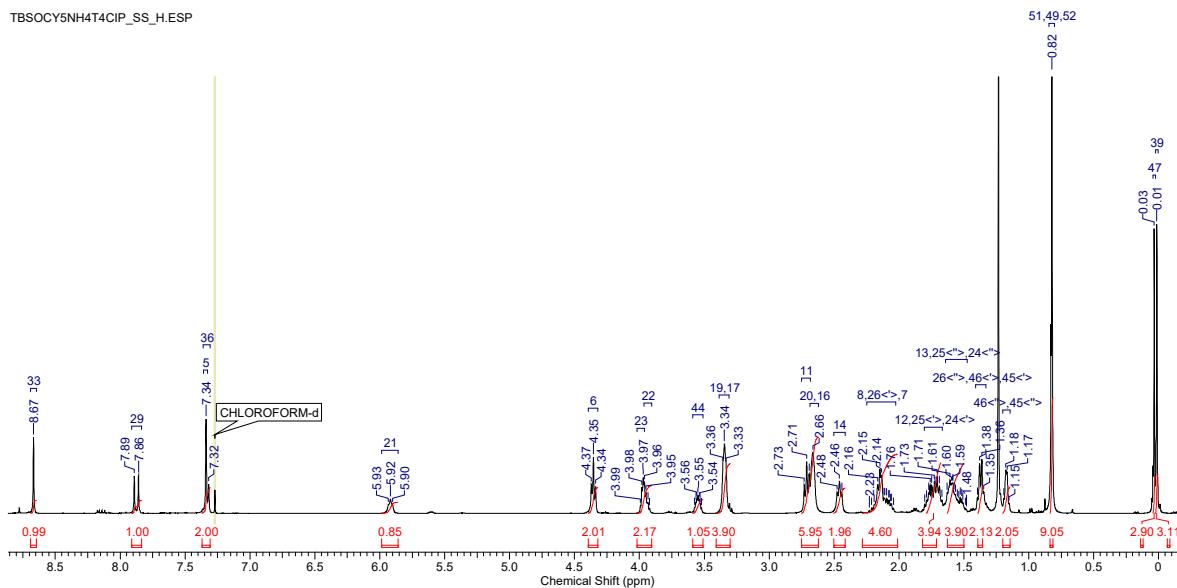
**6.34 4-Azido-*N*-((1*S*,2*S*)-2-((*tert*-butyldimethylsilyl)oxy)cyclopentyl)butanamide
144**



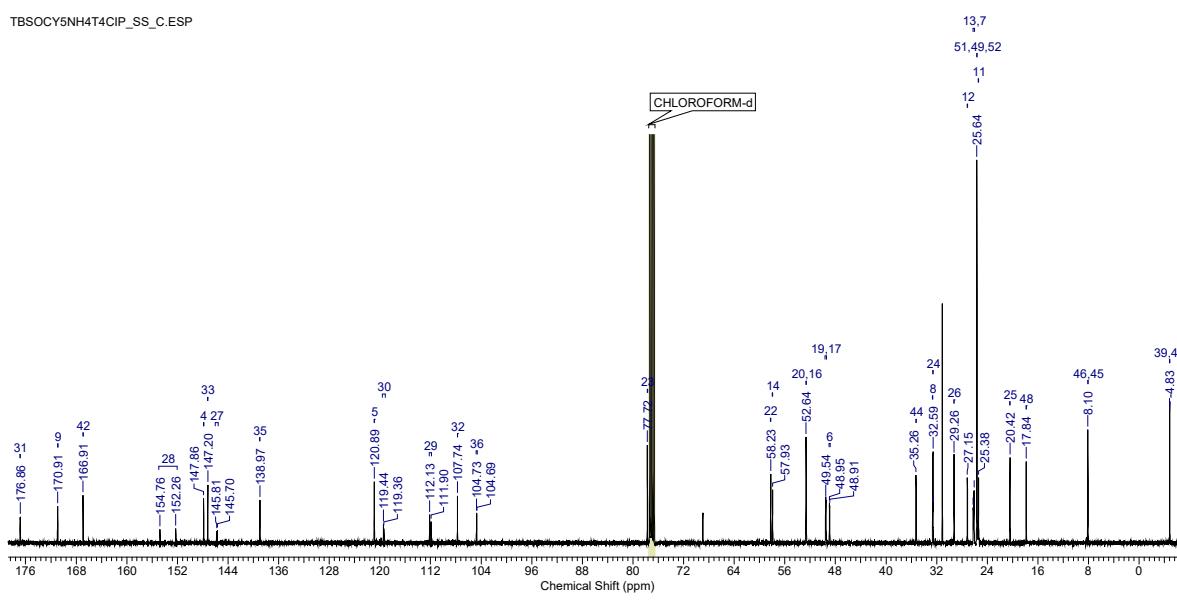
6.35 7-(4-(4-(1-(4-(((1*S*,2*S*)-2-((*tert*-butyldimethylsilyl)oxy)cyclopentyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 148



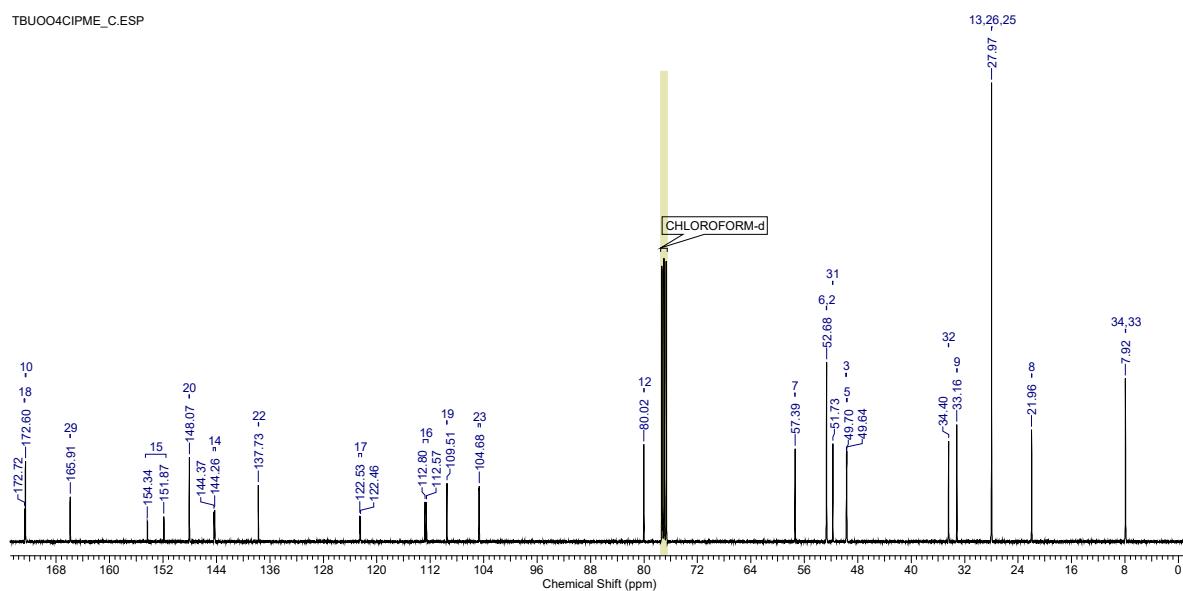
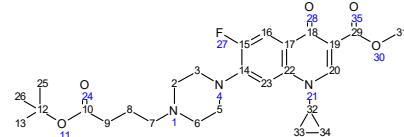
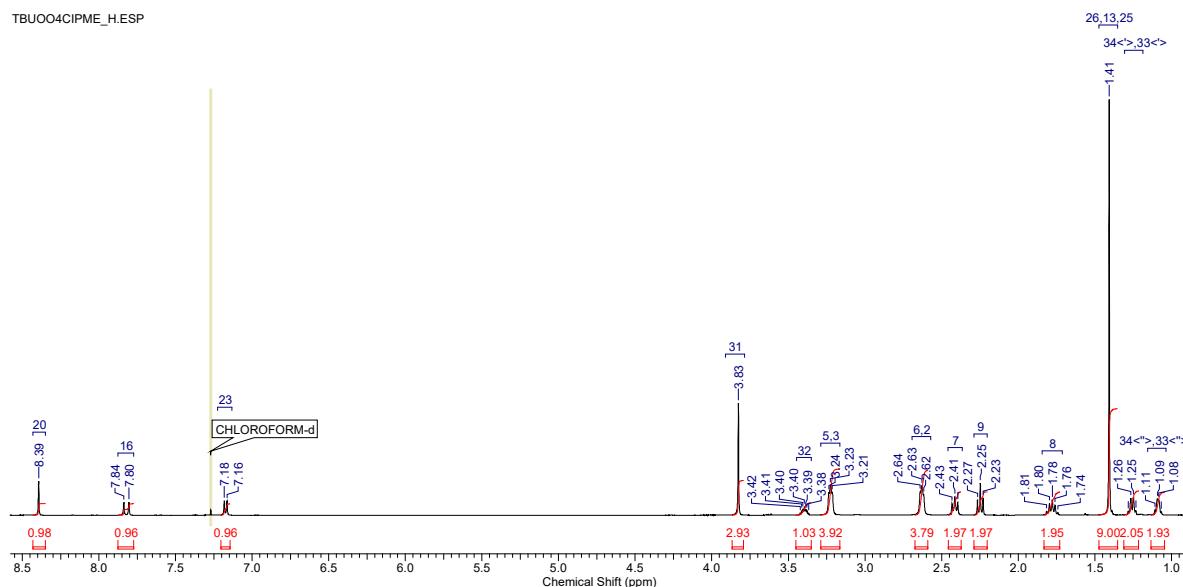
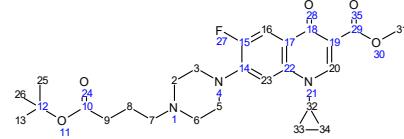
TBSOCY5NH4T4CIP_SS_H.ESP



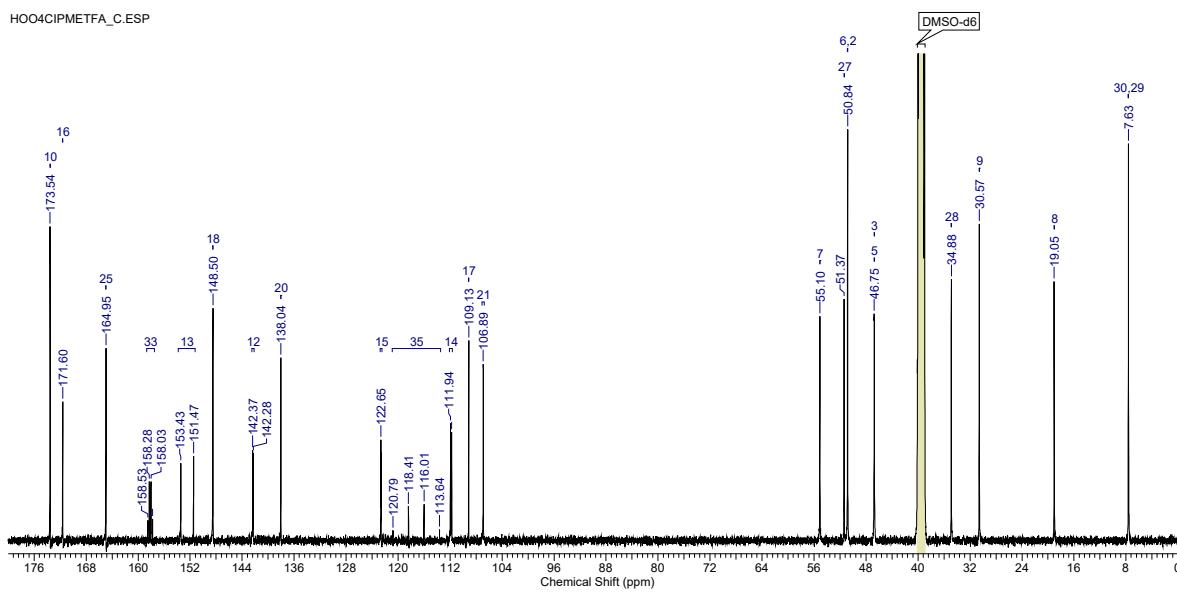
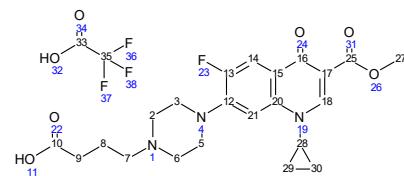
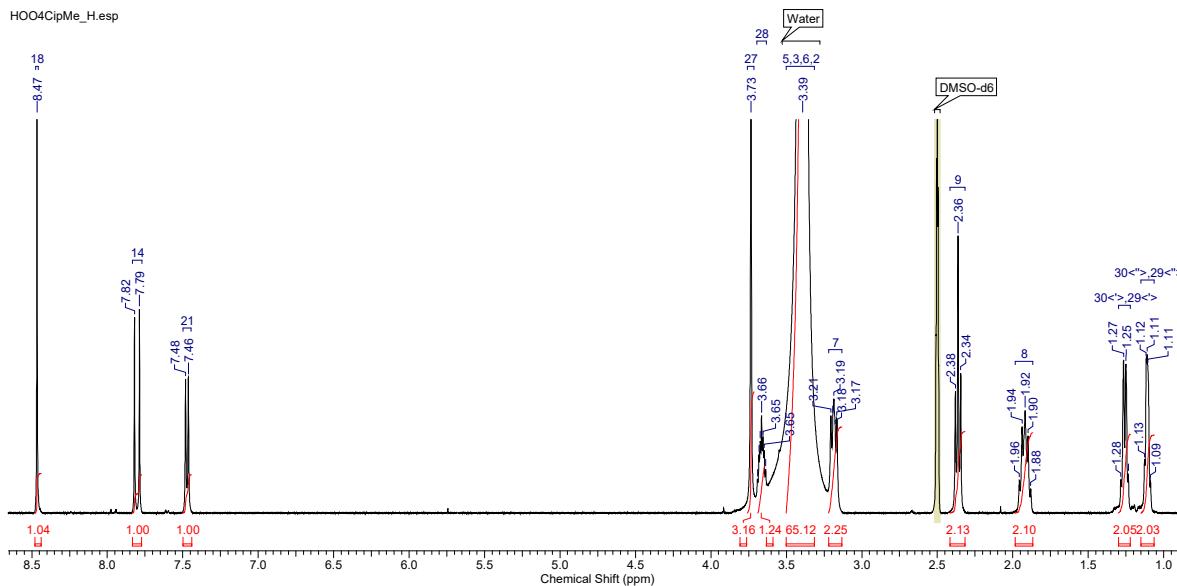
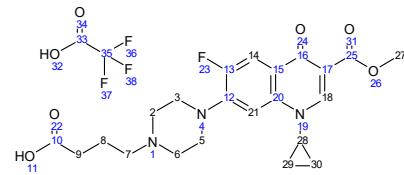
TBSOCY5NH4T4CIP SS C.ESP



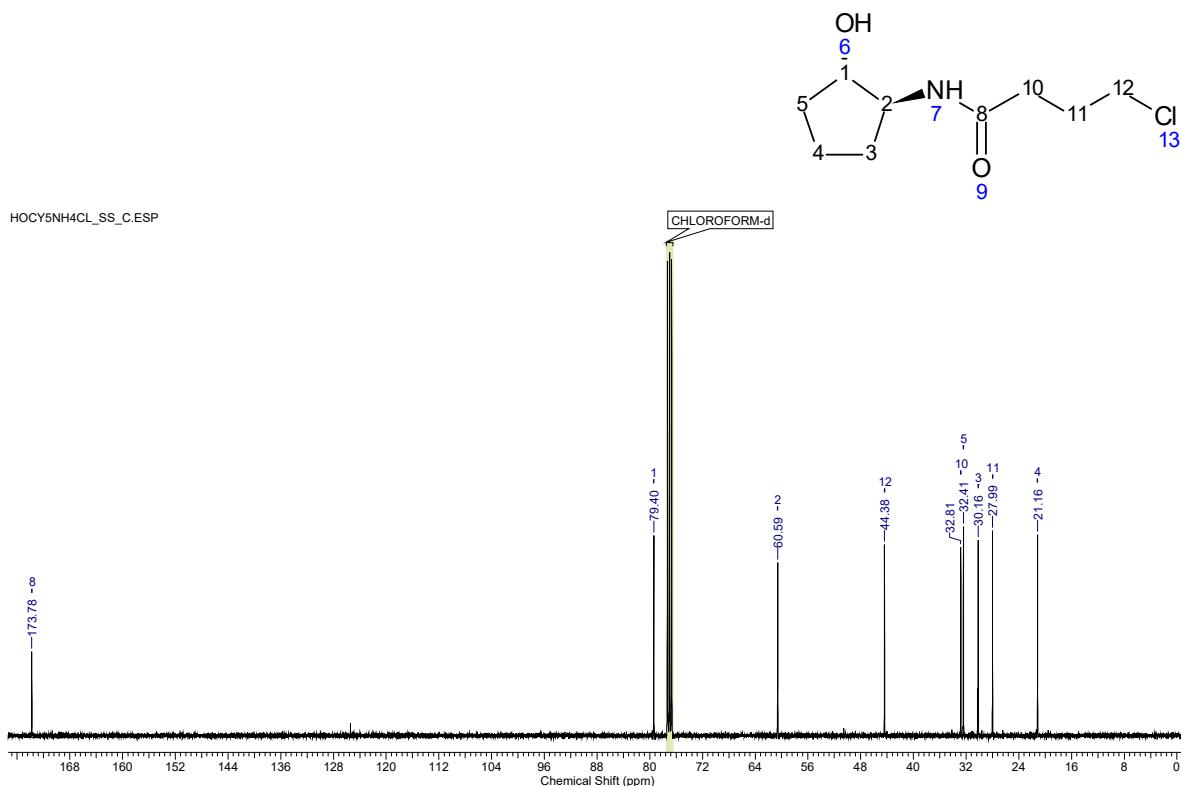
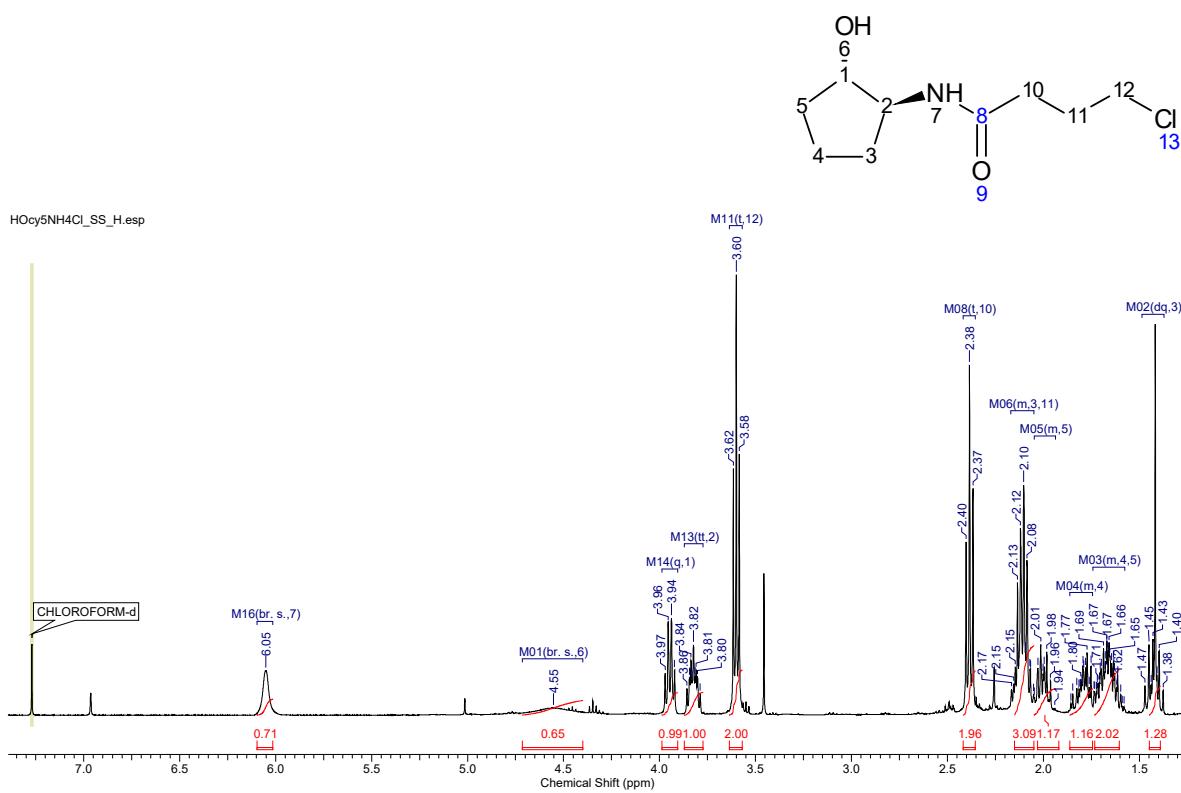
6.36 Methyl 7-(4-(*tert*-butoxy)-4-oxobutyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylate 151



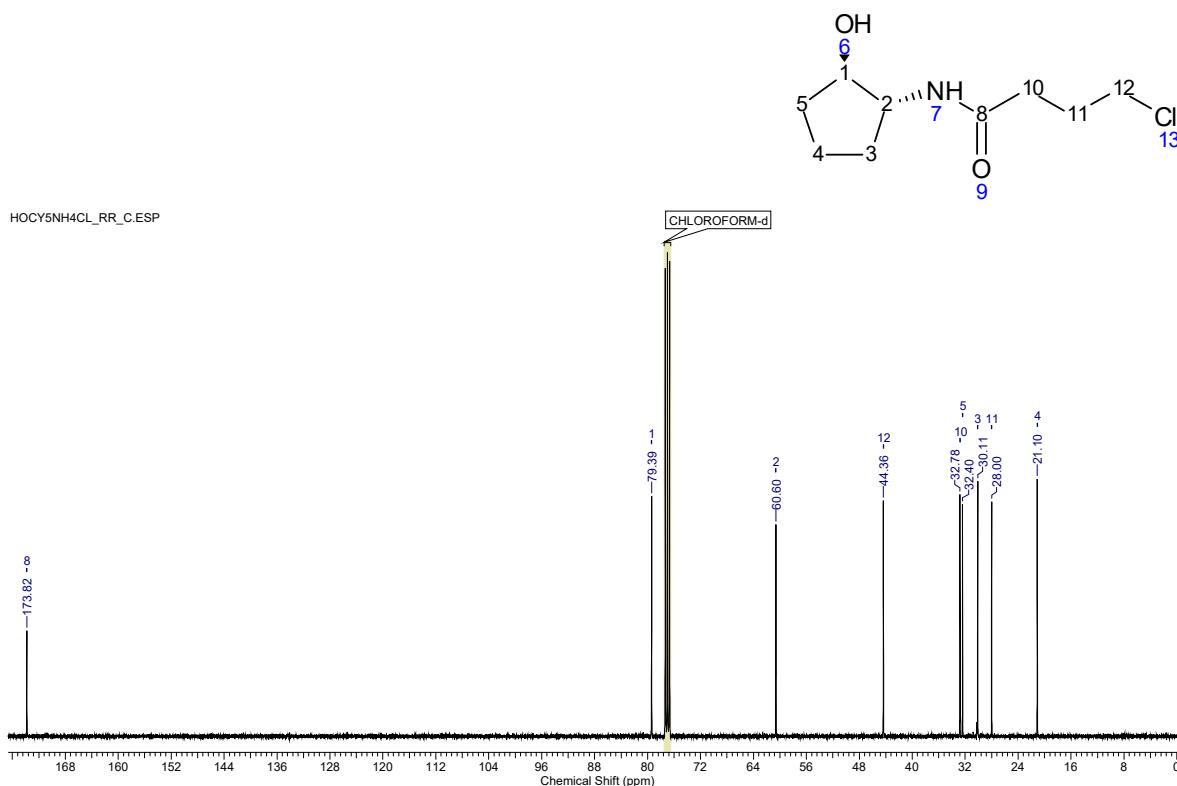
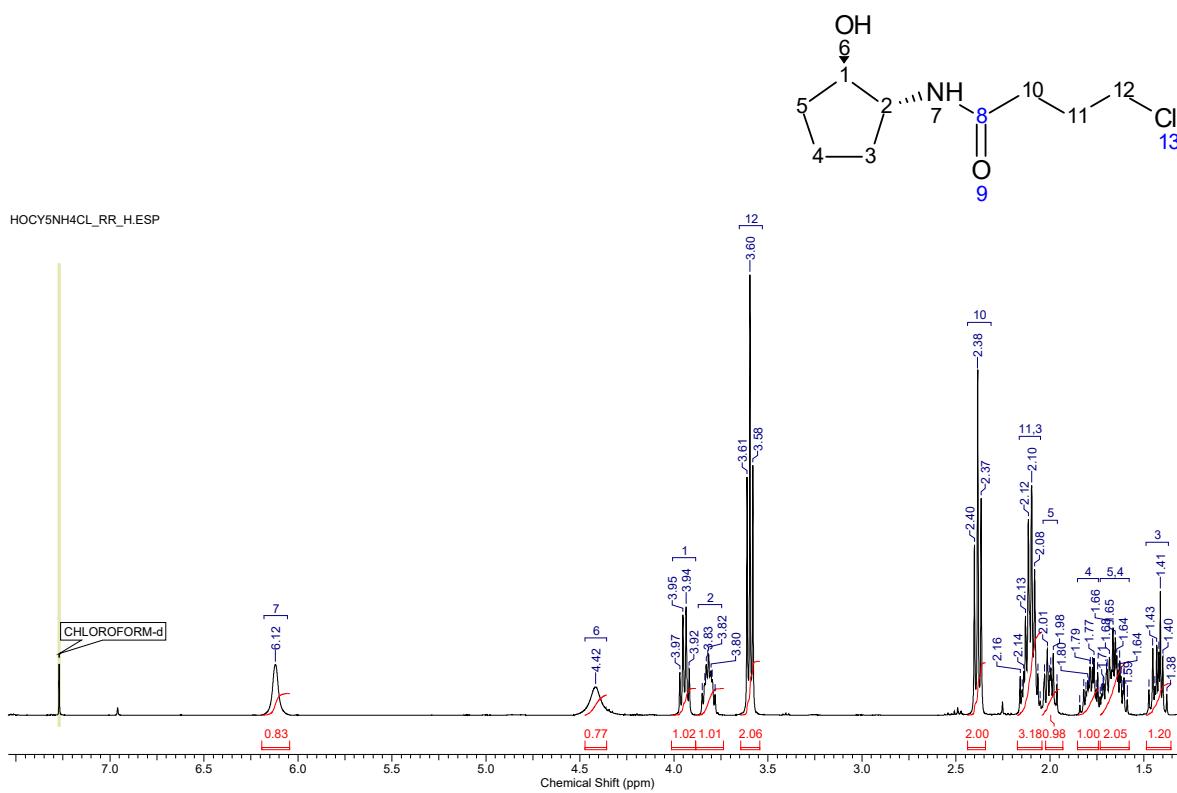
6.37 4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid, trifluoroacetic acid salt 152



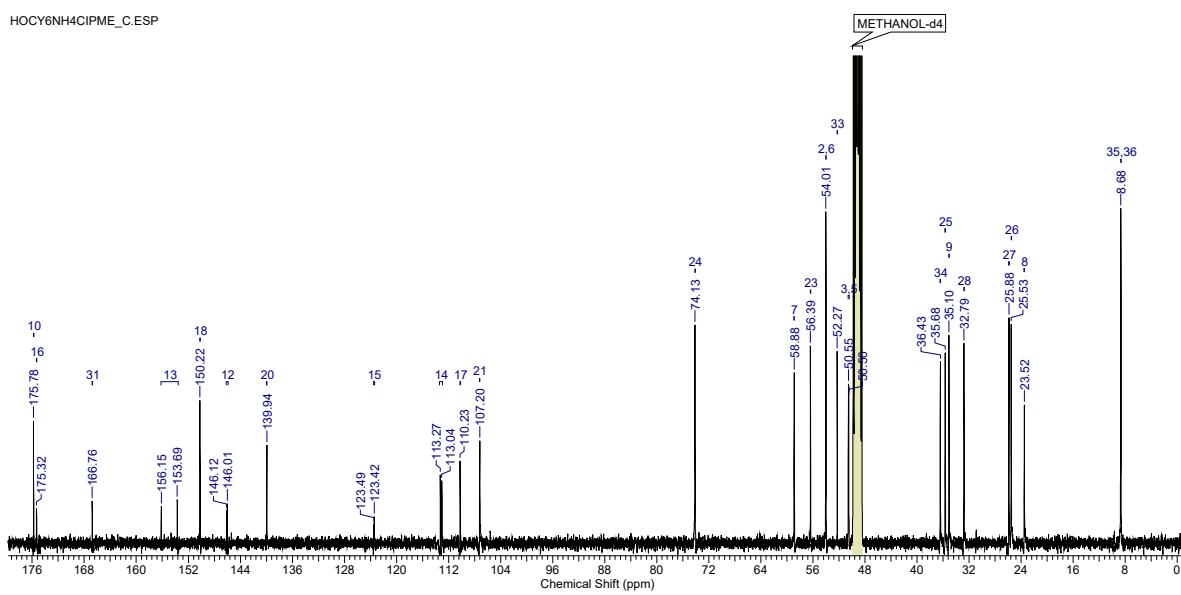
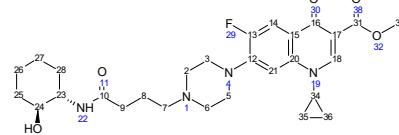
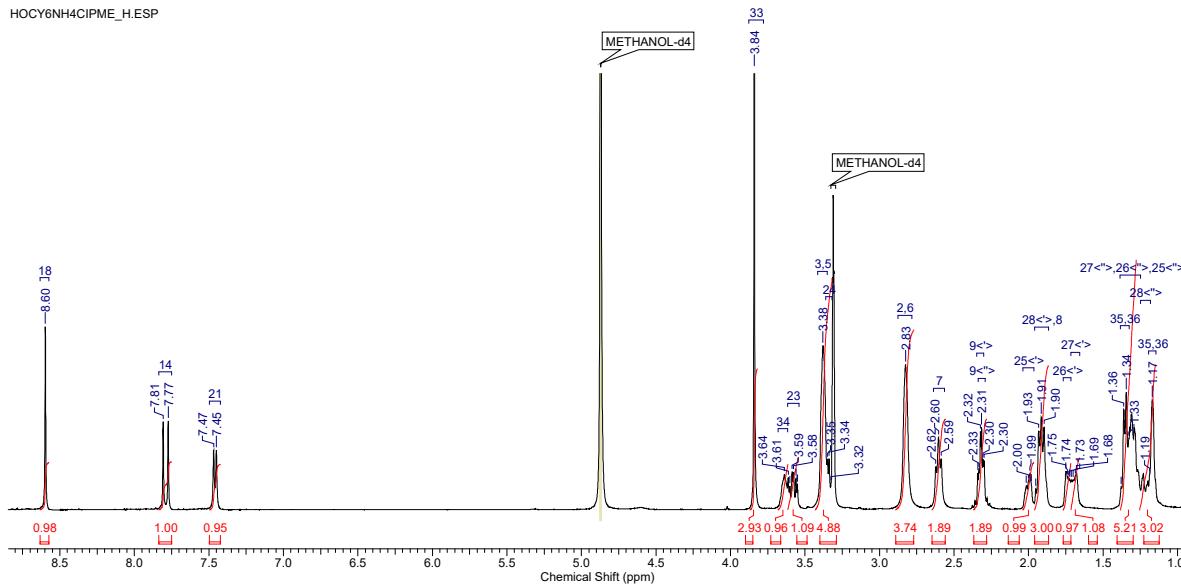
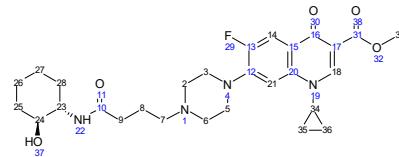
6.38 4-Chloro-*N*-(*(1S,2S)*-2-hydroxycyclopentyl)butanamide 154



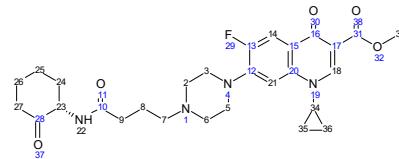
6.39 4-Chloro-*N*-(*1R,2R*)-2-hydroxycyclopentylbutanamide 155



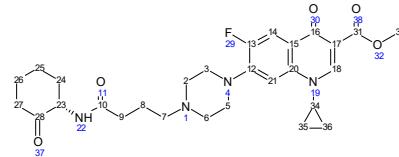
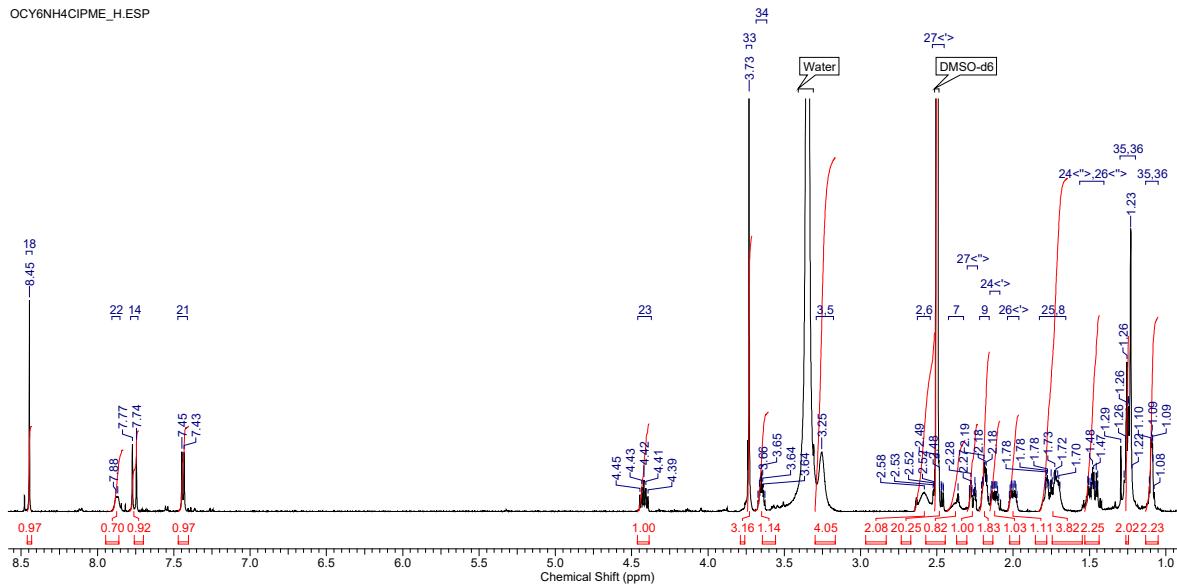
6.40 Methyl 1-cyclopropyl-6-fluoro-7-(4-((*trans*)-2-hydroxycyclohexyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 158



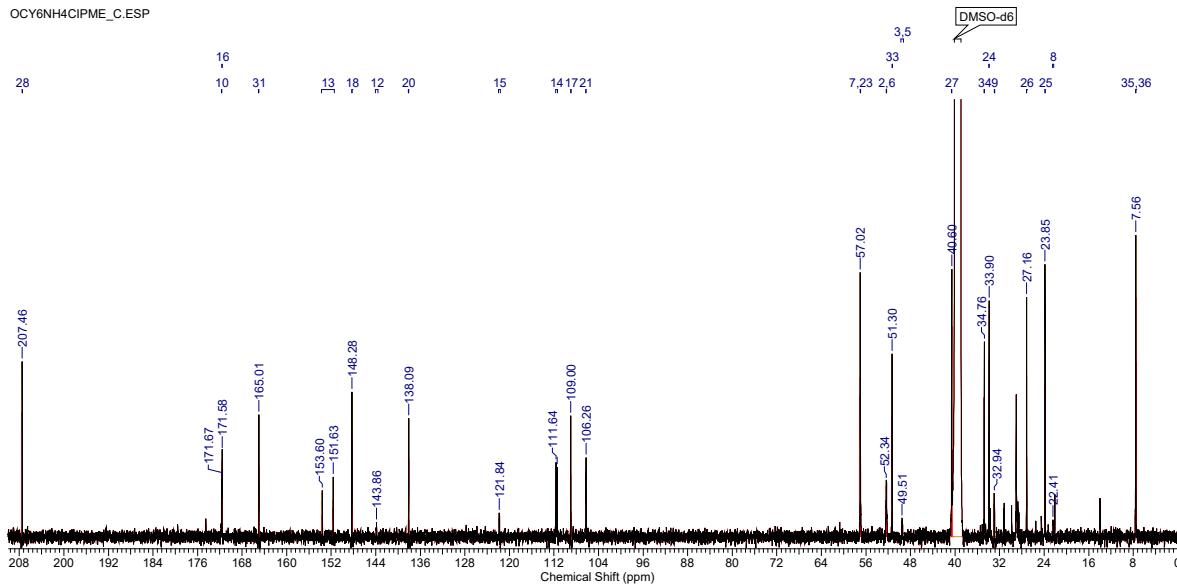
6.41 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxocyclohexyl)amino)-butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 159



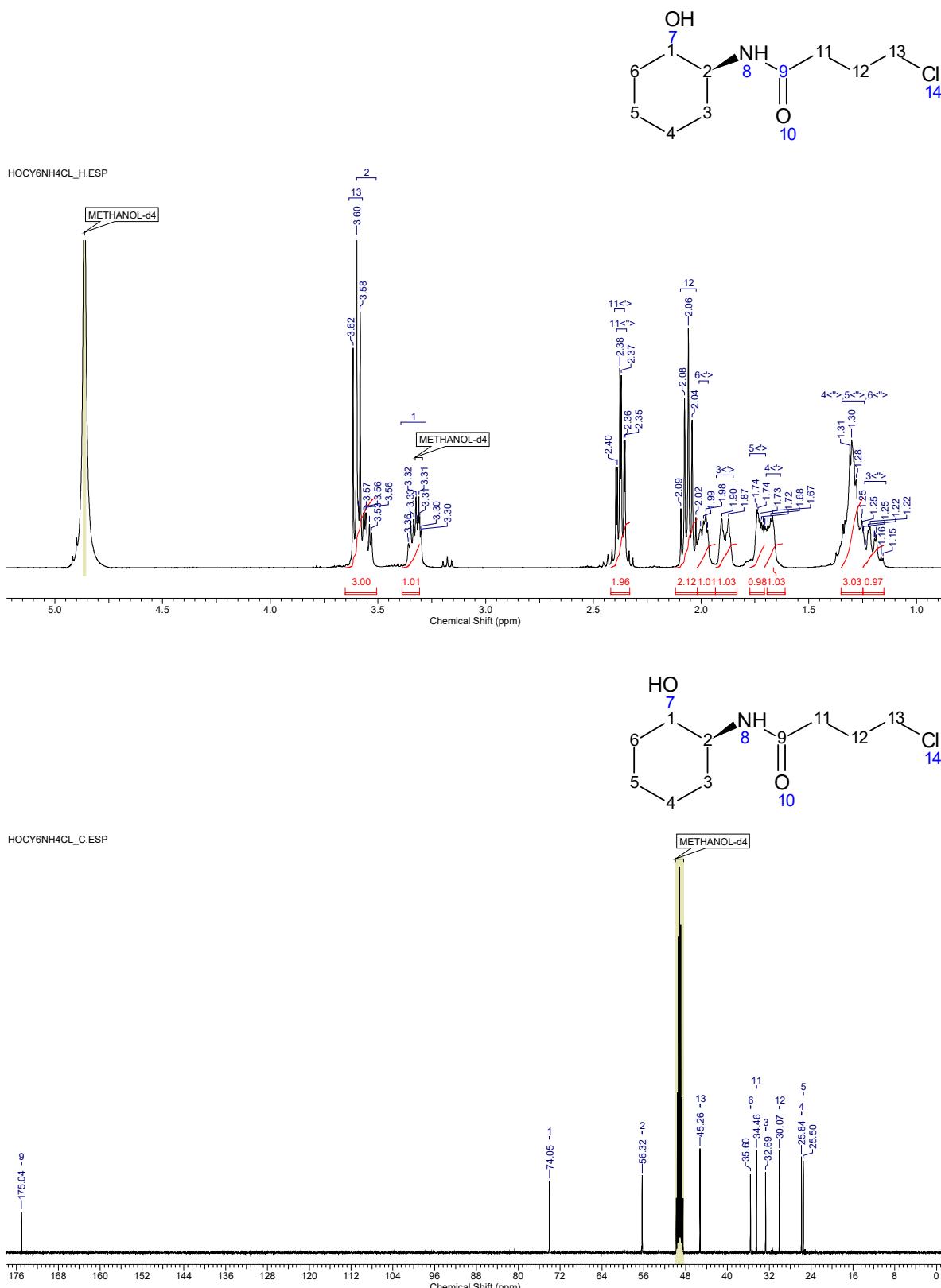
OCY6NH4CIPME_H.ESP



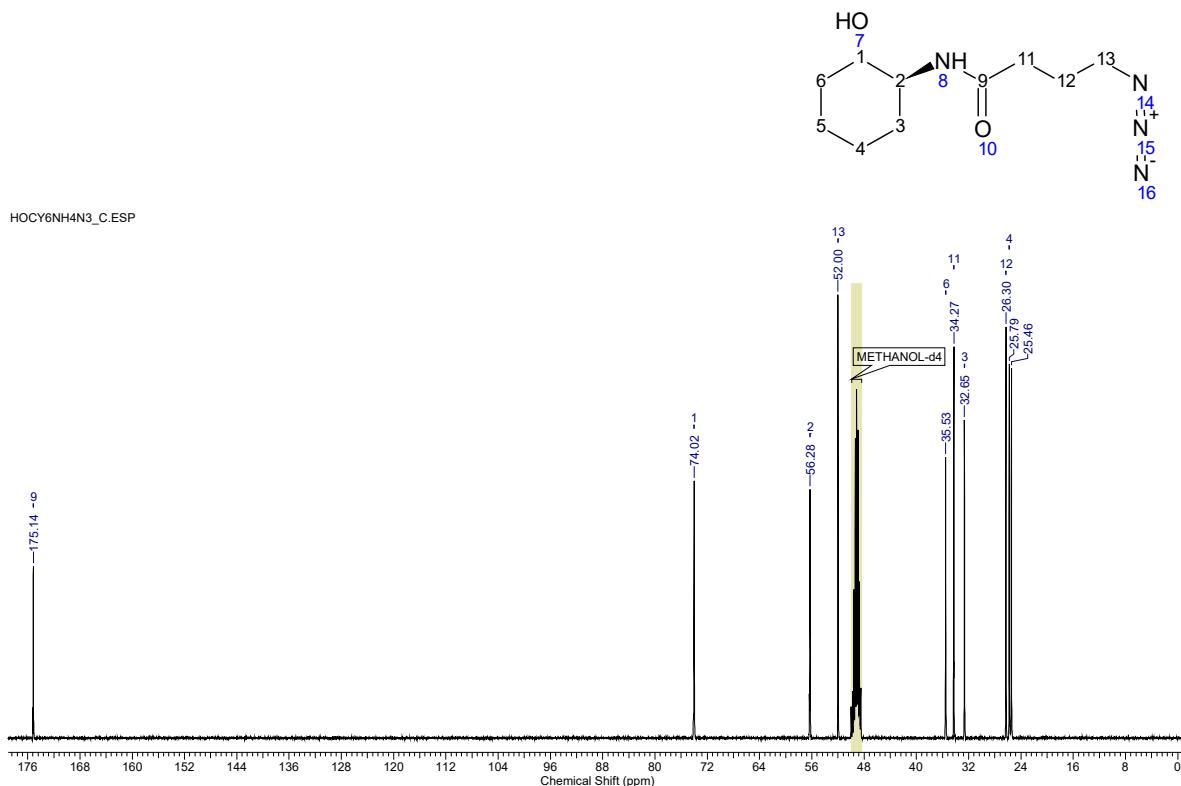
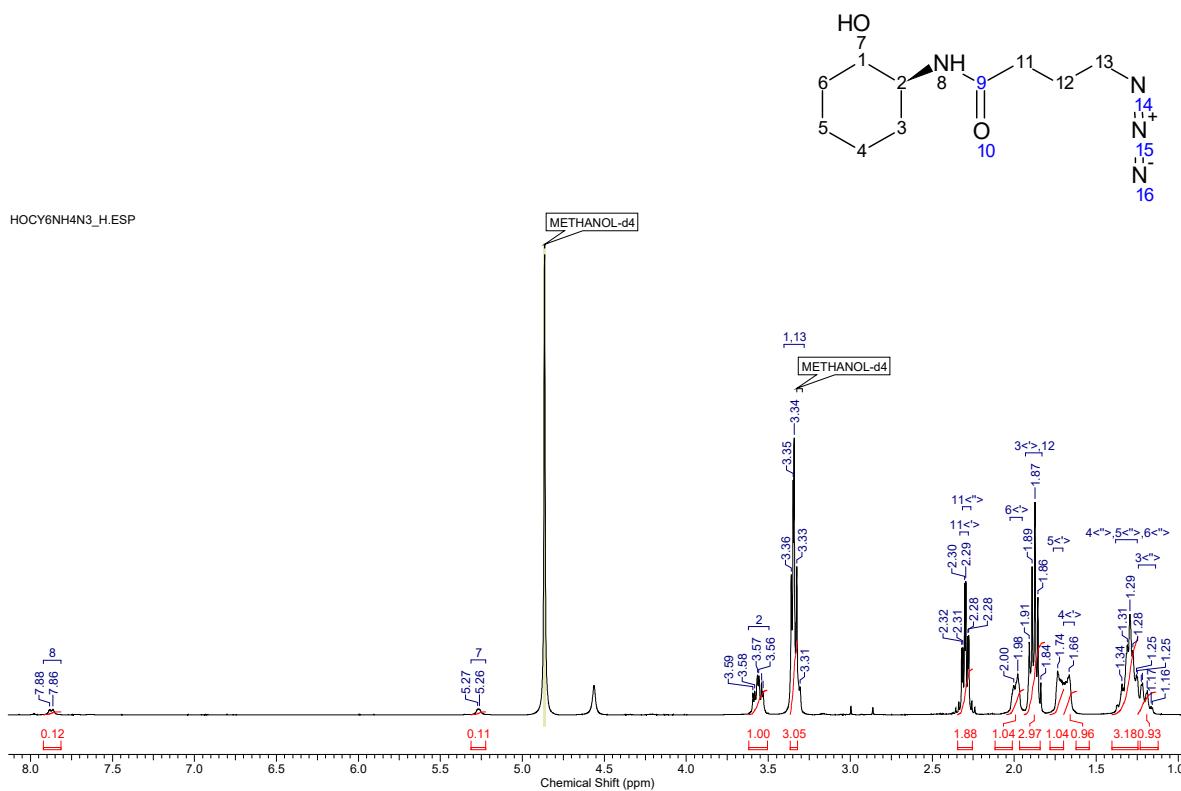
OCY6NH4CIPME_C.ESP



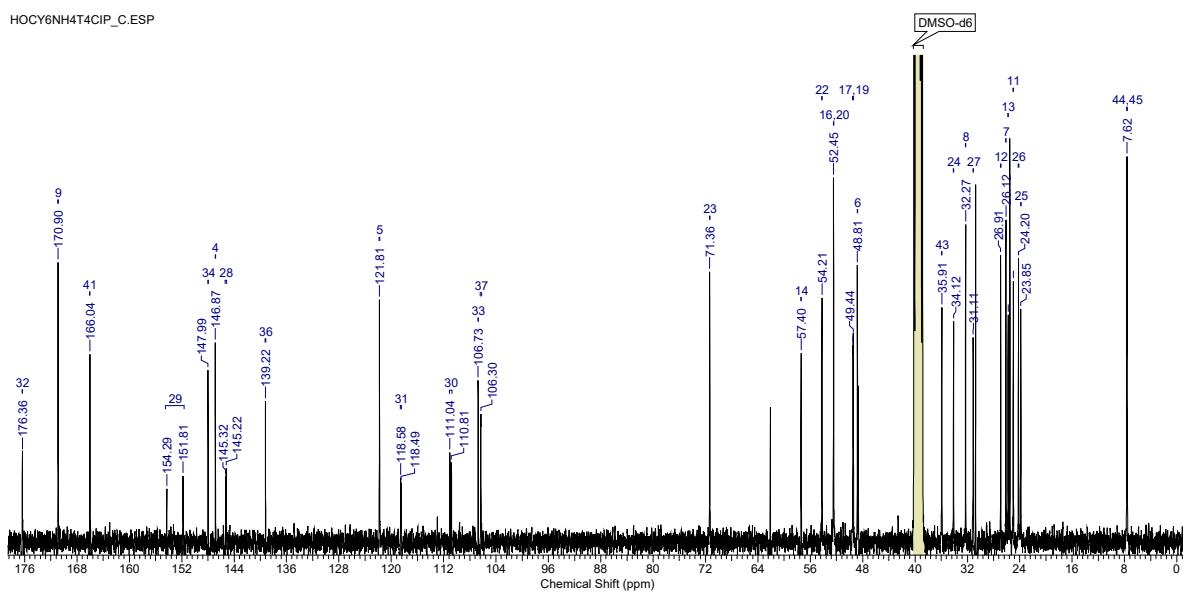
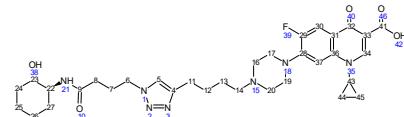
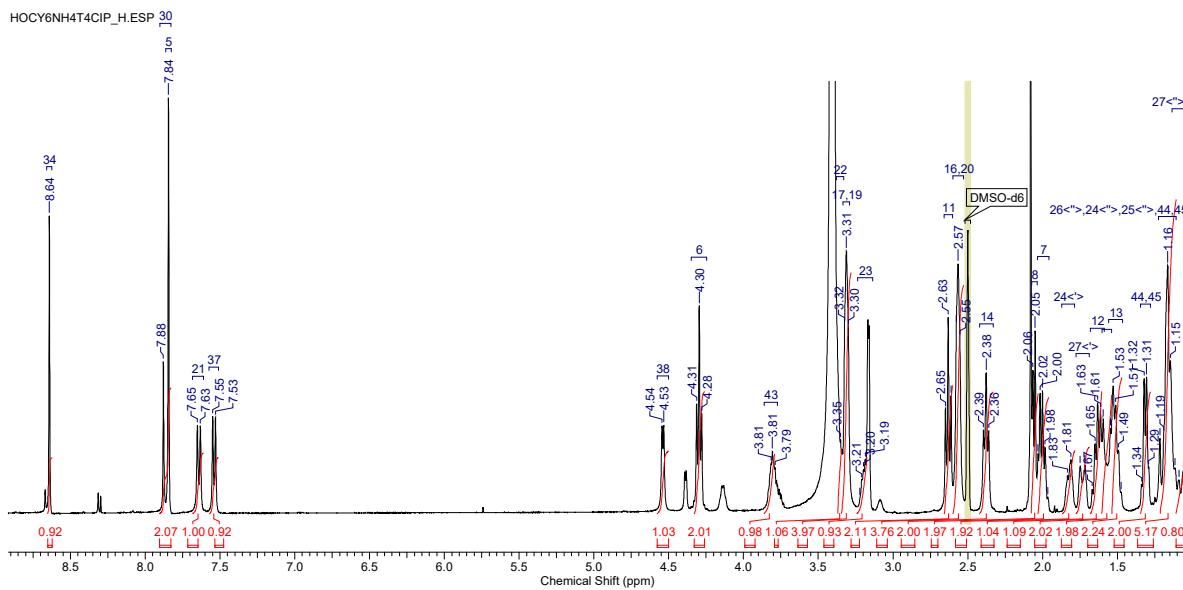
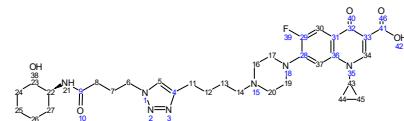
6.42 4-Chloro-*N*-((*trans*)-2-hydroxycyclohexyl)butanamide 160



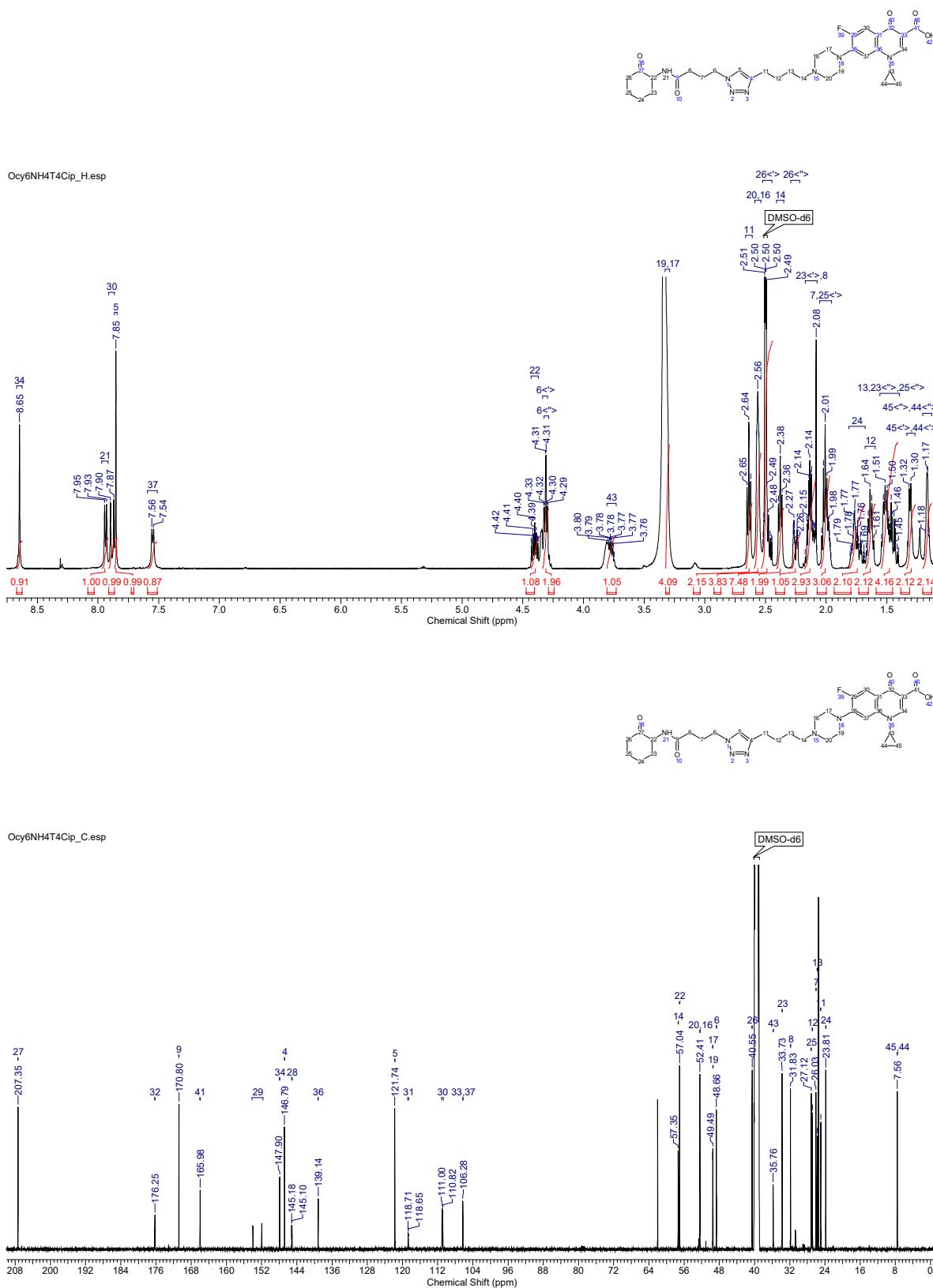
6.43 4-Azido-*N*-((*trans*)-2-hydroxycyclohexyl)butanamide 161



6.44 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((trans)-2-hydroxycyclohexyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquino-line-3-carboxylic acid 162



6.45 1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(4-oxo-4-((2-oxocyclohexyl)amino)butyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 163



7 References

- [1] S. C. Davies, *The Drugs Don't Work: A Global Threat*, Penguin Books Limited. 2013.
- [2] *Antibiotic Resistance Threats in the United States*. 2013.
- [3] A. Fleming. On the antibacterial action of cultures of a penicillium, with special reference to their use in the isolation of *B. influenzae*. *The British Journal of Experimental Pathology*, 10(3):226–236. 1929.
- [4] M. Barber. Staphylococcal infection due to penicillin-resistant strains. *British Medical Journal*, 2(4534):863–865. 1947.
- [5] P. M. Rountree and E. F. Thomson. Incidence of penicillin-resistant and streptomycin-resistant staphylococci in a hospital. *The Lancet*, 254(6577):501–504. 1949.
- [6] P. S. Stewart and J. W. Costerton. Antibiotic resistance of bacteria in biofilms. *The Lancet*, 358(9276):135–138. 2001.
- [7] K. Poole. Efflux-mediated multiresistance in Gram-negative bacteria. *Clinical Microbiology and Infection*, 10(1):12–26. 2004.
- [8] C. Fuda, M. Suvorov, S. B. Vakulenko and S. Mobashery. The basis for resistance to β -lactam antibiotics by penicillin-binding protein 2a of methicillin-resistant *Staphylococcus aureus*. *The Journal of Biological Chemistry*, 279(39):40802–40806. 2004.
- [9] O. Sköld. Sulfonamide resistance: mechanisms and trends. *Drug Resistance Updates*, 3(3):155–160. 2000.
- [10] A. E. Clatworthy, E. Pierson and D. T. Hung. Targeting virulence: a new paradigm for antimicrobial therapy. *Nature Chemical Biology*, 3(9):541–548. 2007.
- [11] S. R. Palumbi. Humans as the World's Greatest Evolutionary Force. *Science*, 293(5536):1786–1790. 2001.
- [12] J. W. Ogle, L. B. Reller and M. L. Vasil. Development of resistance in *Pseudomonas aeruginosa* to imipenem, norfloxacin, and ciprofloxacin during therapy: proof provided by typing with a DNA probe. *The Journal of Infectious Diseases*, 157(4):743–748. 1988.
- [13] P. Huovinen. Resistance to Trimethoprim-Sulfamethoxazole. *Antimicrobial Resistance*, 32(11):1608–1614. 2001.
- [14] M. C. Birmingham, C. R. Rayner, A. K. Meagher, S. M. Flavin, D. H. Batts and J. J. Schentag. Linezolid for the treatment of multidrug-resistant , Gram-positive infections: experience from a compassionate-use program. *Clinical Infectious Diseases*, 36(2):159–168. 2003.
- [15] D. K. Lee, Y. Kim, K. S. Park, J. W. Yang, K. Kim and N. J. Ha. Antimicrobial activity of mupirocin, daptomycin, linezolid, quinupristin/dalfopristin and tigecycline against vancomycin-resistant enterococci (VRE) from clinical isolates in Korea (1998 and 2005). *Journal of Biochemistry and Molecular Biology*, 40(6):881–887. 2007.
- [16] *Oxford English Dictionary*, Oxford University Press. 2014.
- [17] M. B. Miller and B. L. Bassler. Quorum sensing in bacteria. *Annual Review of Microbiology*, 55:165–199. 2001.
- [18] W. C. Fuqua, S. C. Winans and E. P. Greenberg. MINIREVIEW Quorum Sensing in Bacteria : the LuxR-LuxI Family of Cell Density-Responsive Transcriptional Regulatorst. *Journal of Bacteriology*, 176(2):269–275. 1994.

- [19] C. M. Waters and B. L. Bassler. Quorum sensing: cell-to-cell communication in bacteria. *Annual Review of Cell and Developmental Biology*, 21:319–346. 2005.
- [20] S. Atkinson, C.-Y. Chang, R. E. Sockett, M. Camara and P. Williams. Quorum Sensing in *Yersinia enterocolitica* Controls Swimming and Swarming Motility. *Journal of Bacteriology*, 188(4):1451–1461. 2006.
- [21] K.-G. Chan, S. D. Puthucheary, X.-Y. Chan, W.-F. Yin, C.-S. Wong, W.-S. S. Too and K.-H. Chua. Quorum sensing in *Aeromonas* species isolated from patients in Malaysia. *Current Microbiology*, 62(1):167–72. 2011.
- [22] K. Sauer, A. K. Camper, G. D. Ehrlich, J. W. Costerton and D. G. Davies. *Pseudomonas aeruginosa* Displays Multiple Phenotypes during Development as a Biofilm. *Journal of Bacteriology*, 184(4):1140–1154. 2002.
- [23] B. Michael, J. N. Smith, S. Swift and F. Heffron. SdiA of *Salmonella enterica* Is a LuxR Homolog That Detects Mixed Microbial Communities. *Journal of Bacteriology*, 183(19):5733–5742. 2001.
- [24] B. M. M. Ahmer. Cell-to-cell signalling in *Escherichia coli* and *Salmonella enterica*. *Molecular Microbiology*, 52(4):933–945. 2004.
- [25] K. H. Nealson, T. Platt and J. W. Hastings. Cellular Control of the Synthesis and Activity of the Bacterial Luminescent System. *Journal of Bacteriology*, 104(1):313–322. 1970.
- [26] K. L. Visick and E. G. Ruby. *Vibrio fischeri* and its host: it takes two to tango. *Current Opinion in Microbiology*, 9(6):632–638. 2006.
- [27] J. Graf and E. G. Ruby. Host-derived amino acids support the proliferation of symbiotic bacteria. *Proceedings of the National Academy of Sciences*, 95(4):1818–1822. 1998.
- [28] J. D. Lemus and M. J. McFall-Ngai. Alterations in the proteome of the *Euprymna scolopes* light organ in response to symbiotic *Vibrio fischeri*. *Applied and Environmental Microbiology*, 66(9):4091–4097. 2000.
- [29] B. W. Jones and M. K. Nishiguchi. Counterillumination in the Hawaiian bobtail squid, *Euprymna scolopes* Berry (Mollusca: Cephalopoda). *Marine Biology*, 144(6):1151–1155. 2004.
- [30] A. Eberhard, A. L. Burlingame, C. Eberhard, G. L. Kenyon, K. H. Nealson and N. J. Oppenheimer. Structural identification of autoinducer of *Photobacterium fischeri* luciferase. *Biochemistry*, 20(9):2444–2449. 1981.
- [31] H. B. Kaplan and E. P. Greenberg. Diffusion of autoinducer is involved in regulation of the *Vibrio fischeri* luminescence system. *Journal of Bacteriology*, 163(3):1210–1214. 1985.
- [32] M. R. Parsek, D. L. Val, B. L. Hanzelka, J. E. Cronan and E. P. Greenberg. Acyl homoserine-lactone quorum-sensing signal generation. *Proceedings of the National Academy of Sciences*, 96(8):4360–4365. 1999.
- [33] W. T. Watson, T. D. Minogue, D. L. Val, S. B. von Bodman and M. E. A. Churchill. Structural basis and specificity of acyl-homoserine lactone signal production in bacterial quorum sensing. *Molecular Cell*, 9(3):685–694. 2002.
- [34] A. L. Schaefer, B. L. Hanzelka, A. Eberhard and E. P. Greenberg. Quorum sensing in *Vibrio fischeri*: probing autoinducer-LuxR interactions with autoinducer analogs. *Journal of Bacteriology*, 178(10):2897–2901. 1996.

- [35] B. L. Hanzelka and E. P. Greenberg. Evidence that the N-terminal region of the *Vibrio Fischeri* LuxR protein constitutes an autoinducer binding domain. *Journal of Bacteriology*, 177(3):815–817. 1995.
- [36] S. H. Choi and E. P. Greenberg. The C-terminal region of the *Vibrio fischeri* LuxR protein contains an inducer-independent *lux* gene activating domain. *Proceedings of the National Academy of Sciences of the United States of America*, 88(24):11115–11119. 1991.
- [37] S. H. Choi and E. P. Greenberg. Genetic dissection of DNA binding and luminescence gene activation by the *Vibrio fischeri* LuxR protein. *Journal of Bacteriology*, 174(12):4064–4069. 1992.
- [38] J. H. Devine, G. S. Shadel and T. O. Baldwin. Identification of the operator of the lux regulon from the *Vibrio fischeri* strain ATCC7744. *Proceedings of the National Academy of Sciences*, 86(15):5688–5692. 1989.
- [39] J. Engebrecht, K. Nealson and M. Silverman. Bacterial bioluminescence: isolation and genetic analysis of functions from *Vibrio fischeri*. *Cell*, 32(3):773–781. 1983.
- [40] K. L. Visick, J. Foster, J. Doino, M. McFall-Ngai and E. G. Ruby. *Vibrio fischeri lux* genes play an important role in colonization and development of the host light organ. *Journal of Bacteriology*, 182(16):4578–4586. 2000.
- [41] P. V. Dunlap and J. M. Ray. Requirement for autoinducer in transcriptional negative autoregulation of the *Vibrio fischeri luxR* gene in *Escherichia coli*. *Journal of Bacteriology*, 171(6):3549–3552. 1989.
- [42] J.-F. Dubern and S. P. Diggle. Quorum sensing by 2-alkyl-4-quinolones in *Pseudomonas aeruginosa* and other bacterial species. *Molecular BioSystems*, 4(9):882–888. 2008.
- [43] J. T. Hodgkinson. The synthesis of Pseudomonas Quinolone Signal analogues and their effects on quinolone signalling in *Pseudomonas aeruginosa*. PhD thesis, University of Cambridge. 2011.
- [44] P. N. Jimenez, G. Koch, J. A. Thompson, K. B. Xavier, R. H. Cool and W. J. Quax. The multiple signaling systems regulating virulence in *Pseudomonas aeruginosa*. *Microbiology and molecular biology reviews : MMBR*, 76(1):46–65. 2012.
- [45] G. P. Bodey, R. Bolivar, V. Fainstein and L. Jadeja. Infections caused by *Pseudomonas aeruginosa*. *Reviews of Infectious Diseases*, 5(2):279–313. 1983.
- [46] P. Cornelis, *Pseudomonas: Genomics and Molecular Biology*, Caister Academic Press. 2008.
- [47] H. Nikaido. Outer Membrane Barrier as a Mechanism of Antimicrobial Resistance. 33(11):1831–1836. 1989.
- [48] D. J. Evans, D. G. Allison, M. R. W. Brown and P. Gilbert. Susceptibility of *Pseudomonas aeruginosa* and *Escherichia coli* biofilms towards ciprofloxacin : effect of specific growth rate. (August):177–184. 1991.
- [49] M. E. Olson, H. Ceri, D. W. Morck, A. G. Buret and R. R. Read. Biofilm bacteria: formation and comparative susceptibility to antibiotics. *The Canadian Journal of Veterinary Research*, 66:86–92. 2002.
- [50] M. J. Wargo and D. A. Hogan. Examination of *Pseudomonas aeruginosa lasI* regulation and 3-oxo-C12-homoserine lactone production using a heterologous *Escherichia coli* system. *FEMS Microbiology Letters*, 273(1):38–44. 2007.
- [51] J. P. Pearson, K. M. Gray, L. Passador, K. D. Tucker, A. Eberhard, B. H. Iglewski and E. P. Greenberg. Structure of the autoinducer required for expression of *Pseudomonas aeruginosa* virulence genes. *Proceedings of the National Academy of Sciences of the United States of America*, 91(1):197–201. 1994.

- [52] M. J. Gambello and B. H. Iglewski. Cloning and characterization of the *Pseudomonas aeruginosa lasR* gene, a transcriptional activator of elastase expression. *Journal of Bacteriology*, 173(9):3000–3009. 1991.
- [53] E. C. Pesci, J. P. Pearson, P. C. Seed, E. C. Pesci, J. P. Pearson, P. C. Seed and B. H. Iglewski. Regulation of las and rhl quorum sensing in *Pseudomonas aeruginosa*. Regulation of las and rhl Quorum Sensing in *Pseudomonas aeruginosa*. *Strain*, 179(10):3127–3132. 1997.
- [54] M. J. Gambello, S. Kaye and B. H. Iglewski. LasR of *Pseudomonas aeruginosa* Is a Transcriptional Activator of the Alkaline Protease Gene (apr) and an Enhancer of Exotoxin A Expression. 61(4):1180–1184. 1993.
- [55] G. Pessi and D. Haas. Transcriptional Control of the Hydrogen Cyanide Biosynthetic Genes hcnABC by the Anaerobic Regulator ANR and the Quorum-Sensing Regulators LasR and RhlR in *Pseudomonas aeruginosa*. 182(24):6940–6949. 2000.
- [56] D. S. Toder, M. J. Gambello and B. H. Iglewski. *Pseudomonas aeruginosa* LasA: a second elastase under the transcriptional control of lasR. *Molecular Microbiology*, 5(8):2003–2010. 1991.
- [57] A. Latifi, M. Foglino, K. Tanaka, P. Williams and A. Lazdunski. A hierarchical quorum-sensing cascade in *Pseudomonas aeruginosa* links the transcriptional activators LasR and RhIR (VsmR) to expression of the stationary-phase sigma factor RpoS. *Molecular Microbiology*, 21(6):1137–1146. 1996.
- [58] L. A. Gallagher, S. L. McKnight, M. S. Kuznetsova, E. C. Pesci and C. Manoil. Functions required for extracellular quinolone signaling by *Pseudomonas aeruginosa*. *Journal of Bacteriology*, 184(23):6472–6480. 2002.
- [59] D. S. Wade, M. W. Calfee, E. R. Rocha, E. A. Ling, E. Engstrom, J. P. Coleman and E. C. Pesci. Regulation of *Pseudomonas* Quinolone Signal Synthesis in *Pseudomonas aeruginosa*. 187(13):4372–4380. 2005.
- [60] J. M. Brint and D. E. Ohman. Synthesis of multiple exoproducts in *Pseudomonas aeruginosa* is under the control of RhlR-RhlII, another set of regulators in strain PAO1 with homology to the autoinducer-responsive LuxR-LuxI family. *Journal of Bacteriology*, 177(24):7155–7163. 1995.
- [61] J. P. Pearson, L. Passador, B. H. Iglewski and E. P. Greenberg. A second N-acylhomoserine lactone signal produced by *Pseudomonas aeruginosa*. *Proceedings of the National Academy of Sciences*, 92(5):1490–1494. 1995.
- [62] M. K. Winson, M. Camara, A. Latifi, M. Foglino, S. R. Chhabra, M. Daykin, M. Bally, V. Chapon, G. P. Salmond and B. W. Bycroft. Multiple *N*-acyl-L-homoserine lactone signal molecules regulate production of virulence determinants and secondary metabolites in *Pseudomonas aeruginosa*. *Proceedings of the National Academy of Sciences*, 92(20):9427–9431. 1995.
- [63] A. Latifi, M. K. Winson, M. Foglino, B. W. Bycroft, G. S. A. B. Stewart, A. Lazdunski and P. Williams. Multiple homologues of LuxR and LuxI control expression of virulence determinants and secondary metabolites through quorum sensing in *Pseudomonas aeruginosa* PAO1. *Molecular Microbiology*, 17(2):333–343. 1995.
- [64] K. Winzer, C. Falconer, N. C. Garber, S. P. Diggle, M. Camara and P. Williams. The *Pseudomonas aeruginosa* Lectins PA-IL and PA-IIL Are Controlled by Quorum Sensing and by RpoS. 182(22):6401–6411. 2000.
- [65] S. McGrath, D. S. Wade and E. C. Pesci. Dueling quorum sensing systems in *Pseudomonas aeruginosa* control the production of the *Pseudomonas* quinolone signal (PQS). 230:0–7. 2004.

- [66] S. L. McKnight, B. H. Iglewski and E. C. Pesci. The *Pseudomonas* Quinolone Signal Regulates *rhl* Quorum Sensing in *Pseudomonas aeruginosa*. 182(10):2702–2708. 2000.
- [67] E. C. Pesci, J. B. J. Milbank, J. P. Pearson, S. McKnight, A. S. Kende, E. P. Greenberg and B. H. Iglewski. Quinolone signaling in the cell-to-cell communication system of *Pseudomonas aeruginosa*. *Proceedings of the National Academy of Sciences*, 96(20):11229–11234. 1999.
- [68] J. M. Farrow and E. C. Pesci. Two distinct pathways supply anthranilate as a precursor of the *Pseudomonas* quinolone signal. *Journal of Bacteriology*, 189(9):3425–3433. 2007.
- [69] F. Lépine, E. Déziel, S. Milot and L. Rahme. A stable isotope dilution assay for the quantification of the *Pseudomonas* quinolone signal in *Pseudomonas aeruginosa* cultures. *Biochimica et Biophysica Acta (BBA) - General Subjects*, 1622(1):36–41. 2003.
- [70] F. Lépine, S. Milot, E. Déziel, J. He and L. G. Rahme. Electrospray/mass spectrometric identification and analysis of 4-hydroxy-2-alkylquinolines (HAQs) produced by *Pseudomonas aeruginosa*. *Journal of the American Society for Mass Spectrometry*, 15(6):862–869. 2004.
- [71] S. L. Drees and S. Fetzner. PqsE of *Pseudomonas aeruginosa* acts as pathway-specific thioesterase in the biosynthesis of alkylquinolone signaling molecules. *Chemistry & Biology*, 22(5):611–618. 2015.
- [72] J. Lin, J. Cheng, Y. Wang and X. Shen. The *Pseudomonas* Quinolone Signal (PQS): Not Just for Quorum Sensing Anymore. 8(July):1–9. 2018.
- [73] G. Xiao, E. Déziel, J. He, F. Lépine, B. Lesic, M.-H. Castonguay, S. Milot, A. P. Tampakaki, S. E. Stachel and L. G. Rahme. MvfR, a key *Pseudomonas aeruginosa* pathogenicity LTTR-class regulatory protein, has dual ligands. *Molecular Microbiology*, 62(6):1689–99. 2006.
- [74] E. Déziel, S. Gopalan, A. P. Tampakaki, F. Lépine, K. E. Padfield, M. Saucier, G. Xiao and L. G. Rahme. The contribution of MvfR to *Pseudomonas aeruginosa* pathogenesis and quorum sensing circuitry regulation : multiple quorum sensing-regulated genes are modulated without affecting lasRI , rhlRI or the production of N -acyl- L -homoserine lactones. 55:998–1014. 2005.
- [75] S. P. Diggle, K. Winzer, S. R. Chhabra, K. E. Worrall, M. Cámara and P. Williams. The *Pseudomonas aeruginosa* quinolone signal molecule overcomes the cell density-dependency of the quorum sensing hierarchy, regulates *rhl*-dependent genes at the onset of stationary phase and can be produced in the absence of LasR. *Molecular Microbiology*, 50(1):29–43. 2003.
- [76] S. P. Diggle, S. Matthijs, V. J. Wright, M. P. Fletcher, S. R. Chhabra, I. L. Lamont, X. Kong, R. C. Hider, P. Cornelis, M. Cámara and P. Williams. The *Pseudomonas aeruginosa* 4-Quinolone Signal Molecules HHQ and PQS Play Multifunctional Roles in Quorum Sensing and Iron Entrapment. *Chemistry and Biology*, 14(January):87–96. 2007.
- [77] L. Mashburn-Warren, J. Howe, K. Brandenburg and M. Whiteley. Structural requirements of the *Pseudomonas* quinolone signal for membrane vesicle stimulation. *Journal of Bacteriology*, 191(10):3411–3414. 2009.
- [78] C. S. Pereira, J. A. Thompson and K. B. Xavier. AI-2-mediated signalling in bacteria. *FEMS Microbiology Reviews*, 37(2):156–181. 2013.
- [79] H. Li, X. Li, Z. Wang, Y. Fu, Q. Ai, Y. Dong and J. Yu. Autoinducer-2 regulates *Pseudomonas aeruginosa* PAO1 biofilm formation and virulence production in a dose-dependent manner. *BMC Microbiology*, pages 1–8. 2015.

- [80] H. Li, X. Li, C. Song, Y. Zhang and Z. Wang. Autoinducer-2 Facilitates *Pseudomonas aeruginosa* PAO1 Pathogenicity in Vitro and in Vivo. 8(October):1–9. 2017.
- [81] W. R. J. D. Galloway, J. T. Hodgkinson, S. D. Bowden, M. Welch and D. R. Spring. Quorum sensing in Gram-negative bacteria: small-molecule modulation of AHL and AI-2 quorum sensing pathways. *Chemical Reviews*, 111(1):28–67. 2011.
- [82] R. C. Hider and X. L. Kong. Chemistry and biology of siderophores. *Natural Product Reports*, 27(5):637–657. 2010.
- [83] M. R. Seyedsayamdst, S. Cleto, G. Carr, H. Vlamakis, M. João Vieira, R. Kolter and J. Clardy. Mixing and matching siderophore clusters: structure and biosynthesis of serratiochelins from *Serratia* sp. V4. *Journal of the American Chemical Society*, 134(33):13550–135503. 2012.
- [84] T. Zheng and E. M. Nolan. Siderophore-based detection of Fe(III) and microbial pathogens. *Metallooms*, 4(9):866–880. 2012.
- [85] C. J. Carrano and K. N. Raymond. Synthesis and characterization of iron complexes of rhodotorulic acid: a novel dihydroxamate siderophore and potential chelating drug. *Journal of the Chemical Society, Chemical Communications*, (12):501–502. 1978.
- [86] M. B. Hossain, D. L. Eng-Wilmot, R. A. Loghry and D. van der Helm. Circular dichroism, crystal structure, and absolute configuration of the siderophore ferric *N,N',N''*-triacetyl fusarinine, $\text{FeC}_3\text{H}_5\text{N}_6\text{O}_1\text{S}$. *Journal of the American Chemical Society*, 102(18):5766–5773. 1980.
- [87] D. van der Helm, J. R. Baker, D. L. Eng-Wilmot, M. B. Hossain and R. A. Loghry. Crystal structure of ferrichrome and a comparison with the structure of ferrichrome A. *Journal of the American Chemical Society*, 102(12):4224–4231. 1980.
- [88] K. Schlegel, J. Lex, K. Taraz and H. Budzikiewicz. The X-ray structure of the pyochelin Fe^{3+} complex. *Zeitschrift für Naturforschung*, 61c(3-4):263–266. 2006.
- [89] M. G. P. Page. Siderophore conjugates. *Annals of the New York Academy of Sciences*, 1277:115–126. 2013.
- [90] A. Hartmann, H.-P. Fiedler and V. Braun. Uptake and conversion of the antibiotic albomycin by *Escherichia coli* K-12. *European Journal of Biochemistry*, 99(3):517–24. 1979.
- [91] H. Fiedler, F. Walz, A. Döhle and H. Zähner. Albomycin: studies on fermentation, isolation and quantitative determination. *Applied Microbiology and Biotechnology*, 21(6):341–347. 1985.
- [92] G. F. Gause. Recent studies on albomycin, a new antibiotic. *British Medical Journal*, 2(4949):1177–1179. 1955.
- [93] A. Pramanik, U. H. Stroher, J. Krejci, A. J. Standish, E. Bohn, J. C. Paton, I. B. Autenrieth and V. Braun. Albomycin is an effective antibiotic, as exemplified with *Yersinia enterocolitica* and *Streptococcus pneumoniae*. *International Journal of Medical Microbiology*, 297(6):459–469. 2007.
- [94] M. Hannauer, Y. Barda, G. L. A. Mislin, A. Shanzer and I. J. Schalk. The ferrichrome uptake pathway in *Pseudomonas aeruginosa* involves an iron release mechanism with acylation of the siderophore and recycling of the modified desferrichrome. *Journal of Bacteriology*, 192(5):1212–1220. 2010.
- [95] L. Vértesy, W. Aretz, H.-W. Fehlhaber and H. Kogler. Salmycin A–D, Antibiotika aus *Streptomyces violaceus*, DSM 8286, mit Siderophor-Aminoglycosid-Struktur. *Helvetica Chimica Acta*, 78(1):46–60. 1995.

- [96] V. Braun, A. Pramanik, T. Gwinner, M. Köberle and E. Bohn. Sideromycins: tools and antibiotics. *Biometals*, 22:3–13. 2009.
- [97] W. Sackmann, P. Reusser, L. Neipp, F. Kradolfer and F. Gross. Ferrimycin A, a new iron-containing antibiotic. *Antibiotics & Chemotherapy*, 12:34–45. 1962.
- [98] D. Gottlieb and P. D. Shaw, *Mechanism of Action*, Springer. 2012.
- [99] G. Benz, T. Schröder, J. Kurz, C. Wünsche, W. Karl, G. Steffens, J. Pfitzner and D. Schmidt. Constitution of the deferriform of the albomycins $\delta 1$, $\delta 2$ and ϵ . *Angewandte Chemie International Edition in English*, 21(7):527–528. 1982.
- [100] U. Möllmann, L. Heinisch, A. Bauernfeind, T. Köhler and D. Ankel-Fuchs. Siderophores as drug delivery agents: application of the "Trojan Horse" strategy. *Biometals*, 22(4):615–624. 2009.
- [101] C. Dini and J. Aszodi. Synthesis of a dihydroxythiophene analogue of catechosporines. *Bioorganic & Medicinal Chemistry Letters*, 10(4):349–352. 2000.
- [102] T. Kline, M. Fromhold, T. E. McKennon, S. Cai, J. Treiberg, N. Ihle, D. Sherman, W. Schwan, M. J. Hickey, P. Warrener, P. R. Witte, L. L. Brody, L. Goltry, L. M. Barker, S. U. Anderson, S. K. Tanaka, R. M. Shawar, L. Y. Nguyen, M. Langhorne, A. Bigelow, L. Embuscado and E. Naeemi. Antimicrobial effects of novel siderophores linked to β -lactam antibiotics. *Bioorganic & Medicinal Chemistry*, 8(1):73–93. 2000.
- [103] Y. Lu and M. J. Miller. Syntheses and Studies of Multiwarhead Siderophore-5-fluorouridine Conjugates. *Bioorganic & Medicinal Chemistry*, 7(1999):3025–3038. 1999.
- [104] M. Ghosh and M. J. Miller. Synthesis and in vitro antibacterial activity of spermidine-based mixed catechol- and hydroxamate-containing siderophore–vancomycin conjugates. *Bioorganic & Medicinal Chemistry*, 4(1):43–48. 1996.
- [105] M. Ghosh and M. J. Miller. Design, synthesis, and biological evaluation of isocyanurate-based antifungal and macrolide antibiotic conjugates: iron transport-mediated drug delivery. *Bioorganic & Medicinal Chemistry*, 3(11):1519–1525. 1995.
- [106] S. R. Md-Saleh, E. C. Chilvers, K. G. Kerr, S. J. Milner, A. M. Snelling, J. P. Weber, G. H. Thomas, A.-K. Duhme-Klair and A. Routledge. Synthesis of citrate-ciprofloxacin conjugates. *Bioorganic & Medicinal Chemistry Letters*, 19(5):1496–1498. 2009.
- [107] F. Rivault, C. Liébert, A. Burger, F. Hoegy, M. A. Abdallah, I. J. Schalk and G. L. A. Mislin. Synthesis of pyochelin-norfloxacin conjugates. *Bioorganic & Medicinal Chemistry Letters*, 17(3):640–644. 2007.
- [108] C. Ji and M. J. Miller. Chemical syntheses and in vitro antibacterial activity of two desferrioxamine B-ciprofloxacin conjugates with potential esterase and phosphatase triggered drug release linkers. *Bioorganic & Medicinal Chemistry*, 20(12):3828–3836. 2012.
- [109] T. Zheng and E. M. Nolan. Enterobactin-Mediated Delivery of β -Lactam Antibiotics Enhances Antibacterial Activity Against Pathogenic *Escherichia coli*. *Journal of the American Chemical Society*. 2014.
- [110] G. E. Zurenko, S. E. Truesdell, B. H. Yagi, R. J. Mourey and A. L. Laborde. In vitro antibacterial activity and interactions with beta-lactamases and penicillin-binding proteins of the new monocarbam antibiotic U-78608. *Antimicrobial Agents and Chemotherapy*, 34(5):884–8. 1990.

- [111] J. M. Harrington, T. Gootz, M. Flanagan, M. Lall, J. O'Donnell, J. Winton, J. Mueller and A. L. Crumbliss. Characterization of the aqueous iron(III) chelation chemistry of a potential Trojan Horse antimicrobial agent: Chelate structure, stability and pH dependent speciation. *BioMetals*, 25(5):1023–1036. 2012.
- [112] I. J. Schalk and G. L. A. Mislin. Bacterial Iron Uptake Pathways: Gates for the Import of Bactericide Compounds. 2017.
- [113] C. J. McPherson, L. M. Aschenbrenner, B. M. Lacey, K. C. Fahnoe, M. M. Lemmon, S. M. Finegan, B. Tadakamalla, J. P. O. Donnell, J. P. Mueller and A. P. Tomaras. Clinically Relevant Gram-Negative Resistance Mechanisms Have No Effect on the Efficacy of MC-1, a Novel Siderophore-Conjugated. 56(12):6334–6342. 2012.
- [114] A. Ito, T. Sato, M. Ota, M. Takemura, T. Nishikawa, S. Toba, N. Kohira, S. Miyagawa, N. Ishibashi, S. Matsumoto, R. Nakamura, M. Tsuji and Y. Yamanoa. In Vitro Antibacterial Properties of Cefiderocol, a Novel Siderophore Cephalosporin, against Gram-Negative Bacteria. *Antimicrobial Agents and Chemotherapy*, 62(1):1–11. 2018.
- [115] J. S. Yutaka Saisho, Takayuki Katsume, Scott White, Hiroyuki Fukase. Pharmacokinetics, Safety, and Tolerability of Cefiderocol, a Novel Siderophore Cephalosporin for Gram-Negative Bacteria, in Healthy Subjects. *Antimicrobial Agents and Chemotherapy*, (January). 2018.
- [116] F. Paech, S. Messner, J. Spickermann, M. Wind, A. Hortense, S. Hoffmann, A. Therese, W. Brett, A. H. Rachel, J. C. Jeff, W. Marc, S. Krähenbühl and M. Maurer. Mechanisms of hepatotoxicity associated with the monocyclic β -lactam antibiotic BAL30072. *Archives of Toxicology*, 91(11):3647–3662. 2017.
- [117] M. L. Vasil and U. A. Ochsner. The response of *Pseudomonas aeruginosa* to iron: genetics, biochemistry and virulence. *Molecular Microbiology*, 34(3):399–413. 1999.
- [118] C. W. Tornøe, C. Christensen and M. Meldal. Peptidotriazoles on solid phase: [1,2,3]-triazoles by regiospecific copper(I)-catalyzed 1,3-dipolar cycloadditions of terminal alkynes to azides. *The Journal of Organic Chemistry*, 67(9):3057–3064. 2002.
- [119] V. V. Rostovtsev, L. G. Green, V. V. Fokin and K. B. Sharpless. A stepwise Huisgen cycloaddition process: copper(I)-catalyzed regioselective “ligation” of azides and terminal alkynes. *Angewandte Chemie International Edition*, 41(14):2596–2599. 2002.
- [120] C. Florez, J. E. Raab, A. C. Cooke and J. W. Schertzer. Membrane Distribution of the Pseudomonas Quinolone Signal Modulates Outer Membrane Vesicle Production in *Pseudomonas aeruginosa*. pages 1–13. 2017.
- [121] J. P. Pearson, C. Van Delden and B. H. Iglewski. Active Efflux and Diffusion Are Involved in Transport of *Pseudomonas aeruginosa* Cell-to-Cell Signals. *J Bacteriol*, 181(4):1203–1210. 1999.
- [122] K. Evans, L. Passador, R. Srikumar, E. Tsang, J. Nezezon and K. Poole. Influence of the MexAB-OprM multidrug efflux system on quorum sensing in *Pseudomonas aeruginosa*. *Journal of Bacteriology*, 180(20):5443–5447. 1998.
- [123] D. G. Davies, M. R. Parsek, J. P. Pearson, B. H. Iglewski, J. W. Costerton and E. P. Greenberg. The involvement of cell-to-cell signals in the development of a bacterial biofilm. *Science*, 280(5361):295–298. 1998.
- [124] C. M. Oiphant and G. M. Green. Quinolones: a comprehensive review. *American Family Physician*, 65(3):455–464. 2002.

- [125] A. P. Macgowan, M. Wootton and H. A. Holt. The antibacterial efficacy of levofloxacin and ciprofloxacin against *Pseudomonas aeruginosa* assessed by combining antibiotic exposure and bacterial susceptibility. *Journal of Antimicrobial Chemotherapy*, 43:345–349. 1999.
- [126] R. N. Brogden, A. A. Carmine, R. C. Heel, T. M. Speight and G. S. Avery. Trimethoprim: A Review of its Antibacterial Activity, Pharmacokinetics and Therapeutic Use in Urinary Tract Infections. *Drugs*, 23(6):405–430. 1982.
- [127] R. A. Celesk and N. J. Robillard. Factors Influencing the Accumulation of Ciprofloxacin in *Pseudomonas aeruginosa*. 33(11):1921–1926. 1989.
- [128] K. Poole. MINIREVIEW Efflux-Mediated Resistance to Fluoroquinolones in Gram-Negative Bacteria. 44(9):2233–2241. 2000.
- [129] T. R. De Kievit, M. D. Parkins, R. J. Gillis, R. Srikumar, H. Ceri, K. Poole, B. H. Iglewski and D. G. Storey. Multidrug Efflux Pumps: Expression Patterns and Contribution to Antibiotic Resistance in *Pseudomonas aeruginosa* Biofilms. 45(6):1761–1770. 2001.
- [130] T. Köhler, M. Kok, M. Michea-hamzehpour, P. Plesiat, N. Gotoh, T. Nishino, L. K. Curty and J.-c. Pechere. Multidrug Efflux in Intrinsic Resistance to Trimethoprim and Sulfamethoxazole in *Pseudomonas aeruginosa*. 40(10):2288–2290. 1996.
- [131] K. Poole, N. Gotoh, H. Tsujimoto, Q. Zhao, A. Wada, T. Yamasaki, S. Neshat, J.-i. Yamagishi, X.-Z. Li and T. Nishino. Overexpression of the *mexC-mexD-oprJ* efflux operon in *nfxB*-type multidrug-resistant strains of *Pseudomonas aeruginosa*. *Molecular Microbiology*, 21(4):713–725. 1996.
- [132] T. Köhler, M. Michéa-Hamzehpour, U. Henze, N. Gotoh, L. K. Curty and J. C. Pechère. Characterization of MexE-MexF-OprN, a positively regulated multidrug efflux system of *Pseudomonas aeruginosa*. *Molecular Microbiology*, 23(2):345–354. 1997.
- [133] K. Poole. Multidrug Efflux Pumps and Antimicrobial Resistance in *Pseudomonas aeruginosa* and Related Organisms JMMB Symposium. *J. Mol. Microbiol. Biotechnol.*, 3(2):255–264. 2001.
- [134] K. Ganguly, R. Wu, M. Ollivault-Shiflett, P. M. Goodwin, L. A. Silks and R. Iyer. Design, synthesis, and a novel application of quorum-sensing agonists as potential drug-delivery vehicles. *Journal of Drug Targeting*, 19(7):528–539. 2011.
- [135] R. Iyer, K. Ganguly and L. A. Silks. Synthetic analogs of bacterial quorum sensors. Los Alamos National Laboratory. 2012.
- [136] A. Eberhard, C. A. Widrig, P. Mcbath and J. B. Schineller. Analogs of the autoinducer of bioluminescence in *Vibrio fischeri*. *Archives of Microbiology*, 146(1):35–40. 1986.
- [137] L. Passador, K. D. Tucker, K. R. Guertin, M. P. Journet, A. S. Kende and B. H. Iglewski. Functional analysis of the *Pseudomonas aeruginosa* autoinducer PAI. *Journal of Bacteriology*, 178(20):5995–6000. 1996.
- [138] K. M. Smith, Y. Bu and H. Suga. Library Screening for Synthetic Agonists and Antagonists of a *Pseudomonas aeruginosa* Autoinducer. *Chemistry & Biology*, 10(6):563–571. 2003.
- [139] S. R. Chhabra, P. Stead, N. J. Bainton, G. P. Salmond, G. S. Stewart, P. Williams and B. W. Bycroft. Autoregulation of carbapenem biosynthesis in *Erwinia carotovora* by analogues of N-(3-oxohexanoyl)-L-homoserine lactone. *The Journal of Antibiotics*, 46(3):441–454. 1993.

- [140] C. E. McInnis and H. E. Blackwell. Thiolactone modulators of quorum sensing revealed through library design and screening. *Bioorganic & Medicinal Chemistry*, 19(16):4820–4828. 2011.
- [141] G. D. Geske, J. C. O. Neill, D. M. Miller, M. E. Mattmann and H. E. Blackwell. Modulation of Bacterial Quorum Sensing with Synthetic Ligands : Systematic Evaluation of N-Acylated Homoserine Lactones in Multiple Species and New Insights into Their Mechanisms of Action. *Journal of the American Chemical Society*, 129(44):13613–13625. 2007.
- [142] J. C. A. Janssens, K. Metzger, R. Daniels, D. Ptacek, T. Verhoeven, L. W. Habel, J. Vanderleyden, D. E. De Vos and S. C. J. De Keersmaecker. Synthesis of N -Acyl Homoserine Lactone Analogues Reveals Strong Activators of SdiA , the *Salmonella enterica* Serovar. *Applied and Environmental Microbiology*, 73(2):535–544. 2007.
- [143] J. T. Hodgkinson, W. R. J. D. Galloway, M. Wright, I. K. Mati, R. L. Nicholson, M. Welch and D. R. Spring. Design, synthesis and biological evaluation of non-natural modulators of quorum sensing in *Pseudomonas aeruginosa*. *Organic & Biomolecular Chemistry*, 10(30):6032. 2012.
- [144] M. E. Boursier, D. E. Manson, J. B. Combs, E. Helen and H. E. Blackwell. A comparative study of non-native N-acyl L-homoserine lactone analogs in two *Pseudomonas aeruginosa* quorum sensing receptors that share a common native ligand yet inversely regulate virulence. *Bioorganic & Medicinal Chemistry*, pages 1–17. 2018.
- [145] K. M. Smith, Y. Bu and H. Suga. Induction and Inhibition of *Pseudomonas aeruginosa* Quorum Sensing by Synthetic Autoinducer Analogs. *Chemistry & Biology*, 10(1):81–89. 2003.
- [146] G. J. Jog, J. Igarashi and H. Suga. Stereoisomers of *P. aeruginosa* Autoinducer Analog to Probe the Regulator Binding Site. *Chemistry and Biology*. 2006.
- [147] C. Lu, B. Kirsch, C. Zimmer, J. C. De Jong, C. Henn, C. K. Maurer, M. Müsken, S. Häussler, A. Steinbach and R. W. Hartmann. Discovery of antagonists of PqsR, a key player in 2-alkyl-4-quinolone- dependent quorum sensing in *Pseudomonas aeruginosa*. *Chemistry and Biology*, 19(3):381–390. 2012.
- [148] C. Lu, C. K. Maurer, B. Kirsch, A. Steinbach and R. W. Hartmann. Overcoming the unexpected functional inversion of a PqsR antagonist in *Pseudomonas aeruginosa*: An in vivo potent antivirulence agent targeting pqs quorum sensing. *Angewandte Chemie - International Edition*, 53(4):1109–1112. 2014.
- [149] J. Hodgkinson, S. D. Bowden, W. R. J. D. Galloway, D. R. Spring and M. Welch. Structure-activity analysis of the *Pseudomonas* quinolone signal molecule. *Journal of Bacteriology*, 192(14):3833–3837. 2010.
- [150] Y. R. Baker. Investigating quinolone based quorum sensing in *Pseudomonas aeruginosa* using a chemical proteomics approach. PhD thesis, University of Cambridge. 2015.
- [151] T. E. Renau, J. P. Sanchez, J. W. Gage, J. A. Dever, M. A. Shapiro, S. J. Gracheck and J. M. Domagala. Structure-activity relationships of the quinolone antibacterials against mycobacteria: effect of structural changes at N-1 and C-7. *Journal of Medicinal Chemistry*, 39(3):729–735. 1996.
- [152] C. Jing and V. W. Cornish. A fluorogenic TMP-tag for high signal-to-background intracellular live cell imaging. *ACS Chemical Biology*, 8(8):1704–12. 2013.
- [153] Y. R. Baker. Novel Affinity Based Probes for Use in Chemical Proteomic Studies. CPGS thesis. University of Cambridge. 2012.

- [154] J. D. Scribner, D. L. Smith and J. A. McCloskey. Meldrum's Acid in Organic Synthesis. 2. A General and Versatile Synthesis of β -Keto Esters. *The Journal of Organic Chemistry*, 43(10):2087–2088. 1978.
- [155] S. Xu, X. Zhuang, X. Pan, Z. Zhang, L. Duan, Y. Liu, L. Zhang, X. Ren and K. Ding. 1-Phenyl-4-benzoyl-1H-1,2,3-triazoles as Orally Bioavailable Transcriptional Function Suppressors of Estrogen-Related Receptor α . *Journal of Medicinal Chemistry*, 56:4631–4640. 2013.
- [156] J. T. Hodgkinson, W. R. J. D. Galloway, M. Welch and D. R. Spring. Microwave-assisted preparation of the quorum-sensing molecule 2-heptyl-3-hydroxy-4(1H)-quinolone and structurally related analogs. *Nature Protocols*, 7(6):1184–1192. 2012.
- [157] J. Hlaváč, M. Soural, P. Hradil, I. Frys and J. Slouka. The Cleavage of Heterocyclic Compounds in Organic Synthesis II [1] Use of 5-Nitroisatine for Synthesis of Various Nitrogenous Heterocycles. *Journal of Heterocyclic Chemistry*, 41:633–636. 2004.
- [158] P. Hradil, J. Hlaváč and K. Lemr. Preparation of 1,2-disubstituted-3-hydroxy-4(1H)-quinolinones and the influence of substitution on the course of cyclization. *Journal of Heterocyclic Chemistry*, 36(1):141–144. 1999.
- [159] G. Shen, M. Wang, T. R. Welch and B. S. J. Blagg. Design, synthesis, and structure–activity relationships for chimeric inhibitors of Hsp90. *The Journal of Organic Chemistry*, 71(20):7618–7631. 2006.
- [160] D. M. Stacy, S. T. Le Quement, C. L. Hansen, J. W. Clausen, T. Tolker-Nielsen, J. W. Brummond, M. Givskov, T. E. Nielsen and H. E. Blackwell. Synthesis and biological evaluation of triazole-containing N-acyl homoserine lactones as quorum sensing modulators. *Organic & Biomolecular Chemistry*, 11(6):938–954. 2013.
- [161] D. K. Yung, L. G. Chatten and D. P. MacCleod. Potential antiarrhythmic agents I. Synthesis and pharmacological evaluation of some piperazine and ethylenediamine analogs of procaine amide. *Journal of Pharmaceutical Sciences*, 57(12):2073–2080. 1968.
- [162] L. S. Kocsis, E. Benedetti and K. M. Brummond. A Thermal Dehydrogenative Diels-Alder Reaction of Styrenes for the Concise Synthesis of Functionalized Naphthalenes. *Organic Letters*, 14(17):4430–4433. 2012.
- [163] A. F. Abdel-Magid, K. G. Carson, B. D. Harris, C. A. Maryanoff and R. D. Shah. Reductive Amination of Aldehydes and Ketones with Sodium Triacetoxyborohydride. Studies on Direct and Indirect Reductive Amination Procedures(1). *The Journal of Organic Chemistry*, 61(11):3849–3862. 1996.
- [164] P. Reddy and S. Baskaran. Microwave assisted amination of quinolone carboxylic acids: an expeditious synthesis of fluoroquinolone antibacterials. *Tetrahedron Letters*, 42(38):6775–6777. 2001.
- [165] R. Howard. The synthesis of an azido analogue of N-(3-oxododecanoyl)-l-homoserine lactone and an alkynyl analogue of linezolid for use in the synthesis of a library of antibiotic-quorum sensing molecule conjugates. PhD thesis, University of Cambridge. 2015.
- [166] K. Sachin, E.-M. Kim, S.-J. Cheong, H.-J. Jeong, S. T. Lim, M.-H. Sohn and D. W. Kim. Synthesis of N_4' -[^{18}F]fluoroalkylated ciprofloxacin as a potential bacterial infection imaging agent for PET study. *Bioconjugate Chemistry*, 21(12):2282–2288. 2010.
- [167] J. Aubé, Michael S. Wolfe, R. K. Yantiss, S. M. Cook, F. Takusagawa, M. S. Wolfe, R. K. Yantiss, S. M. Cook and F. Takusagawa. Synthesis of Enantiopure N-tert-Butoxycarbonyl-2- aminocycloalkanones. *Synthetic Communications*, 22(20):3003–3012. 1992.

- [168] L. E. Overman and S. Sugai. A Convenient Method for Obtaining trans -2-Aminocyclohexanol and trans -2-Aminocyclopentanol in Enantiomerically Pure Form. *The Journal of Organic Chemistry*, 50:4154–4155. 1985.
- [169] L. E. Overman and S. Sugai. Total Synthesis of (-)-Crinine. Use of Tandem Cationic Aza-Cope Rearrangement/Mannich Cyclizations for the Synthesis of Enantiomerically Pure Amaryllidaceae Alkaloids. *Helvetica Chimica Acta*, 68(3):745–749. 1985.
- [170] X. Wu, P. Ohrngren, A. a. Joshi, A. Trejos, M. Persson, R. K. Arvela, H. Wallberg, L. Vrang, A. Rosenquist, B. B. Samuelsson, J. Unge and M. Larhed. Synthesis, X-ray analysis, and biological evaluation of a new class of stereopure lactam-based HIV-1 protease inhibitors. *Journal of medicinal chemistry*, 55:2724–36. 2012.
- [171] M. T. Robak, M. Trincado and J. A. Ellman. Enantioselective Aza-Henry reaction with an N-sulfinyl urea organocatalyst. *Journal of the American Chemical Society*, 129(49):15110–15111. 2007.
- [172] A. S. Yim and M. Wills. Asymmetric transfer hydrogenation using amino acid derivatives; further studies and a mechanistic proposal. *Tetrahedron*, 61(33):7994–8004. 2005.
- [173] F. Orsini, F. Pelizzoni, M. Sisti and L. Verotta. A CONVENIENT PROCEDURE FOR THE PREPARATION OF *t*-BUTYLDIMETHYLSILYL ETHERS OF HYDROXYAMINO ACIDS. *Organic Preparations and Procedures International*, 21(4):505–508. 1989.
- [174] Y. Kaburagi and Y. Kishi. Operationally simple and efficient workup procedure for TBAF-mediated desilylation: Application to halichondrin synthesis. *Organic Letters*, 9(4):723–726. 2007.
- [175] B. L. Archer, R. F. Hudson and J. E. Wardill. The mechanism of hydrolysis of acid chlorides. Part IV. Salt effects. *J. Chem. Soc.*, (0):888–893. 1953.
- [176] F. Xue and C. T. Seto. Structure-activity studies of cyclic ketone inhibitors of the serine protease plasmin: Design, synthesis, and biological activity. *Bioorganic & Medicinal Chemistry*, 14:8467–8487. 2006.
- [177] H. E. Gottlieb, V. Kotlyar and A. Nudelman. NMR Chemical Shifts of Common Laboratory Solvents as Trace Impurities. *The Journal of Organic Chemistry*, 62(21):7512–7515. 1997.
- [178] T. Persson, T. H. Hansen, T. B. Rasmussen, M. E. Skindersø, M. Givskov and J. Nielsen. Rational design and synthesis of new quorum-sensing inhibitors derived from acylated homoserine lactones and natural products from garlic. *Organic & Biomolecular Chemistry*, 3(2):253–262. 2005.
- [179] R. Srinivasan, L. P. Tan, H. Wu, P.-Y. Yang, K. A. Kalesh and S. Q. Yao. High-throughput synthesis of azide libraries suitable for direct "click" chemistry and in situ screening. *Organic & Biomolecular Chemistry*, 7(9):1821. 2009.
- [180] I. Schiffrers, T. Rantanen, F. Schmidt, W. Bergmans, L. Zani and C. Bolm. Resolution of racemic 2-aminocyclohexanol derivatives and their application as ligands in asymmetric catalysis. *The Journal of Organic Chemistry*, 71(1):2320–2331. 2006.

Todo list

add numbers manually when sorted	15
pre-release paper	21
Boursier2018 pre-release, check for updates	27
put intro in intro	33

weigh Y4Tri then discuss	34
ref	37
link this up	41
link this up	42
should I show the synthesis?	42
check Boursier2018 for print publication details	42
????	70
don't have?	73
don't have?	73
try?	73
works in LCMS see Lois283	92
remove unless very active as not fully characterised	110