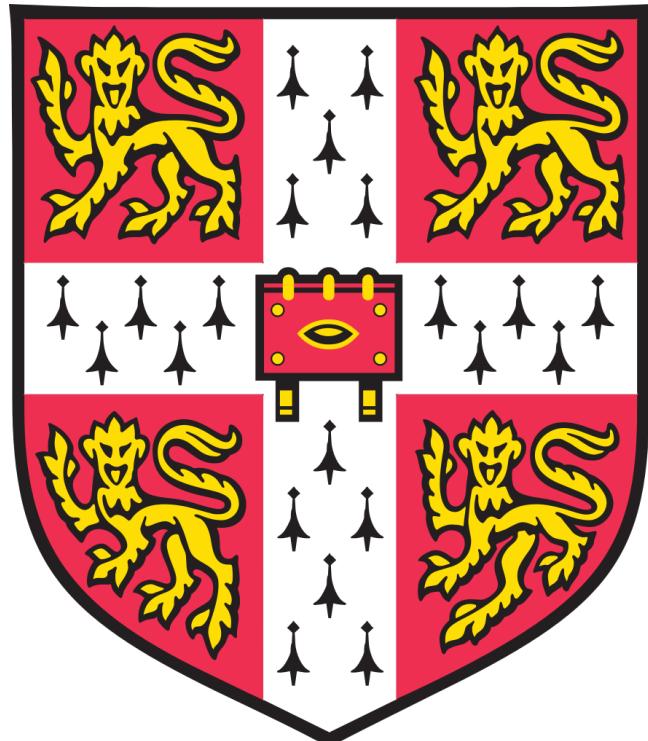


The synthesis and biological evaluation of a library of
autoinducer-antibiotic conjugates

Lois Overvoorde



Sidney Sussex College

University of Cambridge

September 2018

Supervised by Prof. David Spring

This dissertation is submitted for the degree of Doctor of Philosophy

Contents

1 Declaration	8
2 Abstract	9
3 Acknowledgements	10
4 Nomenclature	11
5 Introduction	14
5.1 Antibiotic resistance	14
5.2 Siderophore-antibiotic conjugates	15
5.2.1 Siderophores	16
5.2.2 Sideromycins	18
5.2.3 Synthetic siderophore-antibiotic conjugates	19
5.3 Autoinducer-antibiotic conjugates	22
5.3.1 Quorum sensing	22
5.3.1.1 <i>Vibrio fischeri</i>	22
5.3.1.2 <i>Pseudomonas aeruginosa</i>	24
5.3.2 Autoinducers	26
5.3.3 Autoinducer efflux	27
5.3.4 Antibiotics	27
5.3.5 Antibiotic efflux	28
5.3.6 Conjugate efflux and antibiotic action	28
5.3.7 HSL analogue-ciprofloxacin conjugates	28
6 Project aims and summary	31
7 Results and discussion: autoinducer-antibiotic conjugates	32
7.1 Overview	32
7.1.1 Azido autoinducer derivatives	32
7.1.2 Alkynyl antibiotic derivatives	32
7.1.3 Synthesis of the conjugates	33
7.2 Azido autoinducer derivatives	33
7.2.1 Synthesis of 6-N ₃ -HHQ 36	33
7.2.2 Synthesis of 6-N ₃ -PQS 47	34
7.2.3 Synthesis of the azido C ₄ -HSL derivatives 53 , 56 and 59	36
7.3 Alkynyl antibiotic derivatives	37
7.3.1 Synthesis of the alkynyl ciprofloxacin derivative 66	37
7.3.2 Synthesis of the alkynyl trimethoprim derivative 69	38
7.4 Triazole-linked autoinducer-antibiotic conjugates	39
7.4.1 Optimisation of the click reaction	39
7.4.2 Synthesis of the autoinducer-ciprofloxacin and autoinducer-trimethoprim triazole conjugates	40
7.4.3 Synthesis of homoserine lactone-ciprofloxacin triazole conjugates with cleavable linkers	45

8 Results and discussion: HSL analogue-ciprofloxacin conjugates	46
8.1 Overview	46
8.1.1 Head groups	46
8.1.2 Library construction	47
8.2 Homocysteine thiolactone derivatives	48
8.2.1 Synthesis of methyl ciprofloxacin 98	48
8.2.2 Synthesis of Br-C ₄ -HCTL 100	49
8.2.3 Synthesis of the HCTL-CipMe conjugate 101	49
8.2.4 Synthesis of the HCTL-Cip triazole conjugate 103	50
8.2.5 Synthesis of the cleavable HCTL-Cip triazole conjugate 104	51
8.3 2-Methoxybenzene derivatives	51
8.3.1 Synthesis of Br-C ₄ -2-methoxybenzene 106	51
8.3.2 Synthesis of the 2-methoxybenzene-CipMe conjugate 107	52
8.3.3 Synthesis of the 2-methoxybenzene-Cip triazole conjugate 109	52
8.4 3-Methoxybenzene derivatives	53
8.4.1 Synthesis of Br-C ₄ -3-methoxybenzene 111	53
8.4.2 Synthesis of the 3-methoxybenzene-CipMe conjugate 112	53
8.4.3 Synthesis of the 3-methoxybenzene-Cip triazole conjugate 114	54
8.5 Cyclopentanol derivatives	55
8.5.1 Synthesis of the 2-aminocyclopentan-1-ol head groups 119 and 120	55
8.5.2 Initial branching route	56
8.5.3 TBDMS protection route	58
8.5.3.1 Synthesis of TBDMS-protected (1 <i>S</i> ,2 <i>S</i>)-2-aminocyclopentan-1-ol 119	59
8.5.3.2 Synthesis of Br-C ₄ -cyclopentanol-TBDMS-(<i>SS</i>) 132	60
8.5.3.3 Synthesis of N ₃ -C ₄ -cyclopentanol-TBDMS-(<i>SS</i>) 134 by one-pot reaction	61
8.5.3.4 Synthesis of the (<i>SS</i>)-TBDMS-cyclopentanol-Cip triazole conjugate 138	61
8.5.4 Synthesis of the cyclopentanol-Cip triazole conjugates 128 and 129 via chloride intermediates	62
8.5.5 Synthesis of the cyclopentanol-CipMe conjugates 125 and 126 by peptide coupling	65
8.6 Cyclohexanol derivatives	67
8.6.1 Synthesis of the <i>trans</i> -2-aminocyclohexan-1-ol head group 147	67
8.6.2 Synthesis of the <i>trans</i> -cyclohexanol- and cyclohexanone-CipMe conjugates 148 and 149	68
8.6.3 Synthesis of the <i>trans</i> -cyclohexanol- and cyclohexanone-Cip triazole conjugates 152 and 153	68
9 Experimental	70
9.1 General	70
9.2 Methyl 3-oxodecanoate 31	71
9.3 Methyl (<i>E</i>)-3-((4-((<i>tert</i> -butoxycarbonyl)amino)phenyl)amino)dec-2-enoate 34	72
9.4 6-Amino-2-heptylquinolin-4-ol 35	72
9.5 6-Azido-2-heptylquinolin-4-ol 36	73
9.6 Heptyl magnesium bromide 38	74
9.7 2-Chloro- <i>N</i> -methoxy- <i>N</i> -methylacetamide 41	74
9.8 1-Chlorononan-2-one 42	74
9.9 2-Oxononyl 2-amino-5-nitrobenzoate 44	75
9.10 6-Nitro-2-heptyl-3-hydroxyquinolin-4(1 <i>H</i>)-one 45	76
9.11 6-Amino-2-heptyl-3-hydroxyquinolin-4(1 <i>H</i>)-one 46	76

9.12 6-Azido-2-heptyl-3-hydroxyquinolin-4(1 <i>H</i>)-one 47	77
9.13 (<i>S</i>)-3-Aminodihydrofuran-2(3 <i>H</i>)-one hydrobromide 50	78
9.14 (<i>S</i>)-2-Bromo- <i>N</i> -(2-oxotetrahydrofuran-3-yl)acetamide 52	78
9.15 (<i>S</i>)-2-Azido- <i>N</i> -(2-oxotetrahydrofuran-3-yl)acetamide 53	79
9.16 (<i>S</i>)-4-Bromo- <i>N</i> -(2-oxotetrahydrofuran-3-yl)butanamide 55	80
9.17 (<i>S</i>)-6-Bromo- <i>N</i> -(2-oxotetrahydrofuran-3-yl)hexanamide 58	80
9.18 (<i>S</i>)-6-Azido- <i>N</i> -(2-oxotetrahydrofuran-3-yl)hexanamide 59	81
9.19 Hex-5-ynal 61	82
9.20 <i>tert</i> -Butyl 4-(hex-5-yn-1-yl)piperazine-1-carboxylate 63	82
9.21 1-(Hex-5-yn-1-yl)piperazine 64	83
9.22 1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 66	84
9.23 4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenol 67	85
9.24 5-(4-(Hex-5-yn-1-yloxy)-3,5-dimethoxybenzyl)pyrimidine-2,4-diamine 69	85
9.25 Optimised general procedure for the click reaction	86
9.26 (<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 70	86
9.27 (<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 75	88
9.28 (<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 76	89
9.29 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 78	90
9.30 (<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 82	91
9.31 (<i>S</i>)-6-(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 83	92
9.32 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 85	93
9.33 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 87	94
9.34 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 98	95
9.35 4-Bromo- <i>N</i> -(2-oxotetrahydrothiophen-3-yl)butanamide 100	96
9.36 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 101	96
9.37 4-Azido- <i>N</i> -(2-oxotetrahydrothiophen-3-yl)butanamide 102	97
9.38 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 103	98
9.39 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 104	99
9.40 4-Bromo- <i>N</i> -(2-methoxyphenyl)butanamide 106	100
9.41 Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-((2-methoxyphenyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 107	101
9.42 4-Azido- <i>N</i> -(2-methoxyphenyl)butanamide 108	102
9.43 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 109	103

9.44 4-Bromo- <i>N</i> -(3-methoxyphenyl)butanamide 111	104
9.45 Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-((3-methoxyphenyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 112	105
9.46 4-Azido- <i>N</i> -(3-methoxyphenyl)butanamide 113	106
9.47 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 114	106
9.48 (1 <i>S</i> ,2 <i>S</i>)-2-(((<i>S</i>)-1-Phenylethyl)amino)cyclopentan-1-ol 117 and (1 <i>R</i> ,2 <i>R</i>)-2-(((<i>S</i>)-1-phenylethyl)amino)cyclopentan-1-ol 118	108
9.49 (1 <i>S</i> ,2 <i>S</i>)-2-Aminocyclopentan-1-ol 119	109
9.50 (1 <i>R</i> ,2 <i>R</i>)-2-Aminocyclopentan-1-ol 120	110
9.51 4-Azido- <i>N</i> -((1 <i>S</i> ,2 <i>S</i>)-2-hydroxycyclopentyl)butanamide 123	110
9.52 4-Azido- <i>N</i> -((1 <i>R</i> ,2 <i>R</i>)-2-hydroxycyclopentyl)butanamide 124	111
9.53 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 125	112
9.54 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 126	113
9.55 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 127	114
9.56 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 128	115
9.57 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 129	116
9.58 (1 <i>S</i> ,2 <i>S</i>)-2-((<i>tert</i> -Butyldimethylsilyl)oxy)cyclopentan-1-amine 130	117
9.59 4-Azido- <i>N</i> -((1 <i>S</i> ,2 <i>S</i>)-2-((<i>tert</i> -butyldimethylsilyl)oxy)cyclopentyl)butanamide 134	118
9.60 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 138	119
9.61 Methyl 7-(4-(4-(<i>tert</i> -butoxy)-4-oxobutyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylate 141	120
9.62 4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid trifluoroacetate 142	121
9.63 4-Chloro- <i>N</i> -((1 <i>S</i> ,2 <i>S</i>)-2-hydroxycyclopentyl)butanamide 144	121
9.64 4-Chloro- <i>N</i> -((1 <i>R</i> ,2 <i>R</i>)-2-hydroxycyclopentyl)butanamide 145	122
9.65 (<i>trans</i>)-2-Aminocyclohexan-1-ol 147	123
9.66 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 148	124
9.67 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxocyclohexyl)amino)-butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 149	125
9.68 4-Chloro- <i>N</i> -((<i>trans</i>)-2-hydroxycyclohexyl)butanamide 150	126
9.69 4-Azido- <i>N</i> -((<i>trans</i>)-2-hydroxycyclohexyl)butanamide 151	126
9.70 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 152	127
9.71 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 153	128
10 NMR spectra	130
10.1 (<i>S</i>)-4-Bromo- <i>N</i> -(2-oxotetrahydrofuran-3-yl)butanamide 55	130

10.2 (<i>S</i>)-6-Bromo- <i>N</i> -(2-oxotetrahydrofuran-3-yl)hexanamide 58	131
10.3 (<i>S</i>)-6-Azido- <i>N</i> -(2-oxotetrahydrofuran-3-yl)hexanamide 59	132
10.4 <i>tert</i> -Butyl 4-(hex-5-yn-1-yl)piperazine-1-carboxylate 63	133
10.5 1-(Hex-5-yn-1-yl)piperazine 64	134
10.6 1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 66	135
10.7 5-(4-(Hex-5-yn-1-yloxy)-3,5-dimethoxybenzyl)pyrimidine-2,4-diamine 69	136
10.8 (<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 70	137
10.9 (<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 75	138
10.10 (<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 76	139
10.111-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 78	140
10.12 (<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 82	141
10.13 (<i>S</i>)-6-(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 83	142
10.146-(4-(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 85	143
10.152-(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 87	144
10.164-Bromo- <i>N</i> -(2-oxotetrahydrothiophen-3-yl)butanamide 100	145
10.17Methyl 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 101	146
10.184-Azido- <i>N</i> -(2-oxotetrahydrothiophen-3-yl)butanamide 102	147
10.191-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)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 103	148
10.201-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 104	149
10.214-Bromo- <i>N</i> -(2-methoxyphenyl)butanamide 106	150
10.22Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-(2-methoxyphenyl)amino)-4-oxobutyl)-piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 107	151
10.231-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 109	152
10.244-Bromo- <i>N</i> -(3-methoxyphenyl)butanamide 111	153
10.25Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-(3-methoxyphenyl)amino)-4-oxobutyl)-piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 112	154
10.264-Azido- <i>N</i> -(3-methoxyphenyl)butanamide 113	155
10.271-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 114	156
10.284-Azido- <i>N</i> -((1 <i>S</i> ,2 <i>S</i>)-2-hydroxycyclopentyl)butanamide 123	157
10.294-Azido- <i>N</i> -((1 <i>R</i> ,2 <i>R</i>)-2-hydroxycyclopentyl)butanamide 124	158
10.30Methyl 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 125	159

10.31Methyl 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 126	160
10.321-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 128	161
10.331-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 129	162
10.344-Azido- <i>N</i> -((1 <i>S</i> ,2 <i>S</i>)-2-((<i>tert</i> -butyldimethylsilyl)oxy)cyclopentyl)butanamide 134	163
10.357-(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 138	164
10.36Methyl 7-(4-(4-(<i>tert</i> -butoxy)-4-oxobutyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylate 141	165
10.374-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid, trifluoroacetic acid salt 142	166
10.384-Chloro- <i>N</i> -((1 <i>S</i> ,2 <i>S</i>)-2-hydroxycyclopentyl)butanamide 144	167
10.394-Chloro- <i>N</i> -((1 <i>R</i> ,2 <i>R</i>)-2-hydroxycyclopentyl)butanamide 145	168
10.40Methyl 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 148	169
10.41Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxocyclohexyl)amino)-butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 149	170
10.424-Chloro- <i>N</i> -((<i>trans</i>)-2-hydroxycyclohexyl)butanamide 150	171
10.434-Azido- <i>N</i> -((<i>trans</i>)-2-hydroxycyclohexyl)butanamide 151	172
10.441-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 152	173
10.451-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 153	174

11 References

175

1 Declaration

This dissertation describes work carried out in the Department of Chemistry, University of Cambridge under the supervision of Prof. David Spring, and in the Department of Biochemistry, University of Cambridge under the supervision of Dr Martin Welch. This dissertation is the result of my own work and includes nothing that is the outcome of work done in collaboration except as specified in the text. The dissertation does not exceed the word limit specified by the Physics and Chemistry Degree Committee.

Lois Overvoorde September 2018

2 Abstract

Bacterial resistance to antibiotics is becoming a serious global health threat, and the discovery of new, safe and effective antibiotics is required urgently.¹⁻³ A new class of antibiotic, namely siderophore-antibiotic conjugates, has shown promise in initial studies.^{4,5} Siderophores are used by bacteria for iron uptake, and so attaching antibiotics to them allows the antibiotic to be carried across cell membranes. This study investigates conjugates designed using a similar approach, but using bacterial autoinducers⁶ instead of siderophores. Autoinducers are required for coordination of bacterial behaviours and are involved in the control of swarming, virulence factor production and biofilm formation.⁷

The library was synthesised in two halves which were then coupled together using a copper(I)-catalysed azide-alkyne cycloaddition.^{8,9} The autoinducers were functionalised with azide groups and the antibiotics were functionalised with alkynes. The quorum sensing molecules produced by *Pseudomonas aeruginosa* were investigated as it is a significant human pathogen¹⁰ which displays high resistance to many antibiotics¹¹ and uses quorum sensing to coordinate its group behaviours.¹² Azido analogues of these autoinducers were coupled with alkyne analogues of ciprofloxacin, which was chosen as it is commonly used against *P. aeruginosa*¹³ but resistance to it is developing,¹⁴ and trimethoprim. It was hoped that the autoinducers would aid retention of the antibiotic in the cell, thus potentially increasing its potency or even restoring its efficacy against resistant strains.

analogues

3 Acknowledgements

Firstly, I would like to thank David Spring for the opportunity to work on this very interesting topic. I would also like to thank Hannah Sore for guidance and support through the later stages of the project, and Eddy Sotelo and Bin Yu for collaboration and useful discussions. Thank you to Mark Eldridge and Suzie Forrest for help with learning biochemical techniques, to Martin Welch for guidance and advice on data interpretation and especially to Tom O'Brien for stepping in to do some of the testing. Thanks also to Matt Pond, Melvyn Orriss, Nic Davies and Naomi Hobbs for help with equipment and glassware and to Jill Vaughan and Tommy Osberger for proof-reading. Most importantly, I would like to thank Yssy Baker for proof-reading, help, support, advice and encouragement.

4 Nomenclature

<i>J</i>	Coupling constant in Hz
<i>m/z</i>	Mass to charge ratio in Daltons
<i>R_f</i>	Retention factor
Ac	Acetate
AIP	Autoinducing peptide
aq.	Aqueous
atm	Atmosphere(s)
BHL	Butyryl homoserine lactone = C ₄ -HSL 19
Boc	<i>tert</i> -Butyloxycarbonyl
Cip	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
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

HO_Bt 1-Hydroxybenzotriazole

HPLC High-performance liquid chromatography

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

M Molar

m.p. Melting point

Me Methyl

MIC Minimum inhibitory concentration

min Minute(s)

mol Mole(s)

Ms Methanesulfonyl

NMP *N*-Methyl-2-pyrrolidone

NMR Nuclear magnetic resonance

OdDHL *N*-(3-Oxododecanoyl)-homoserine lactone = 3-oxo-C₁₂-HSL **20**

P.E. Petroleum ether

PAI-1 *Pseudomonas* autoinducer 1 = 3-oxo-C₁₂-HSL **20**

PAI-2 *Pseudomonas* autoinducer 2 = C₄-HSL **19**

Pd/C Palladium on carbon

PQS *Pseudomonas* Quinolone Signal

Q-TOF Quadrupole time-of-flight

r.t. Room temperature

s Second(s)

SAM *S*-adenosyl-L-methionine

SAR Structure activity relationship

sat. Saturated

sp. Species

TBAF Tetrabutylammonium fluoride

TBDMS *tert*-Butyldimethylsilyl

TEA Triethylamine

Tf Trifluoromethanesulfonyl

TFA Trifluoroacetic acid

THF Tetrahydrofuran

THPTA Tris(3-hydroxypropyltriazolylmethyl)amine

TLC Thin layer chromatography

TMS Trimethylsilyl

Ts *para*-Toluenesulfonyl

UV Ultraviolet

5 Introduction

5.1 Antibiotic resistance

Antibiotics add, on average, twenty years to a person's life.² 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 Suffolk² is well known to many scientists. The initial serendipitous discovery of penicillin occurred in 1928 and was reported in 1929,¹⁵ 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.^{16,17} 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.^{2,3}

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.¹⁸
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*.¹¹
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.¹⁹
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 *para*-aminobenzoic acid - a process which is blocked by sulfonamides.²⁰

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.^{21–26}

The current pipeline of new antibiotics is widely thought to be worryingly inadequate.^{27–29} Significant changes in how we use the antibiotics we already have, as well as investments in the discovery of new ones, are required. Antibiotics currently in late-stage clinical trials nearly all rely on non-novel mechanisms of action,²⁷ and so it is almost inevitable that resistance to them will develop quickly, as it has done for their predecessors.

There is therefore increasing interest in treatments which would not easily provoke the development of resistance.³⁰ These treatments often target bacterial virulence rather than killing bacteria outright, hence decreasing selection pressure for resistance.²¹ One obvious target is toxin production, for example, an LpxC inhibitor was shown to prevent lethal *Acinetobacter baumannii* infection in mice, despite being inactive against the bacterium *in vitro*.³¹ This was due to inhibition of lipopolysaccharide shedding, and hence reduced inflammation in the host. Co-ordination of virulence has also been targeted, for example, analogues of *P. aeruginosa* homoserine lactone autoinducers (see 5.3.1) inhibit the production of virulence factors and increase the survival time of mice in a lethal *P. aeruginosa* lung infection model.

A second strategy in novel antibiotic discovery is to enhance or restore activity of a known antibiotic by lessening or avoiding a resistance mechanism. For example, antibiotics are often excluded from cells due to membrane impermeability or efflux. This may be overcome by attaching the antibiotic warhead to a molecule which the cell imports. The most well known examples of such conjugates are antibody-drug conjugates³² in the treatment of cancer, but progress has also made against bacteria. In particular, siderophore-antibiotic conjugates (see 5.2) have been investigated in the hope of hijacking bacterial uptake mechanisms to import antibiotics,⁴ and the autoinducer-antibiotic conjugates in this study may gain activity by avoiding efflux pumps (see 5.3). These conjugates may have competing mechanisms of action: either the antibiotic accumulates in the cell to a greater extent and acts by its usual mechanism, or an important bacterial system must be disrupted to avoid accumulation of the antibiotic, hence leading to decreased fitness and/or loss of virulence.

5.2 Siderophore-antibiotic conjugates

Siderophore-antibiotic conjugates have been receiving attention in recent years as a way to enhance the uptake of known antibiotics.⁴ This section will discuss the role of siderophores, sideromycins (natural siderophore-antibiotic conjugates), and the synthetic siderophore-antibiotic conjugates inspired by them. Many of the ob-

servations made about these molecules could be relevant to the autoinducer-antibiotic conjugates synthesised in this study.

5.2.1 Siderophores

Siderophores are peptides or small molecules used by microorganisms to chelate iron for the purposes of 'iron mining'.³³ 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 1 and Figure 2), possibly so one species can avoid its siderophores being taken up by another species.³⁴

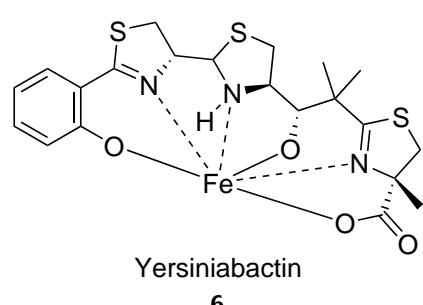
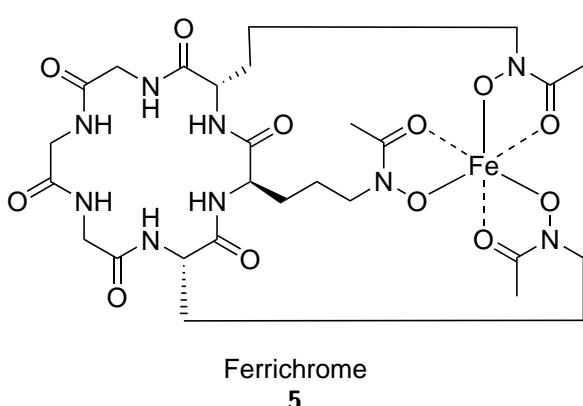
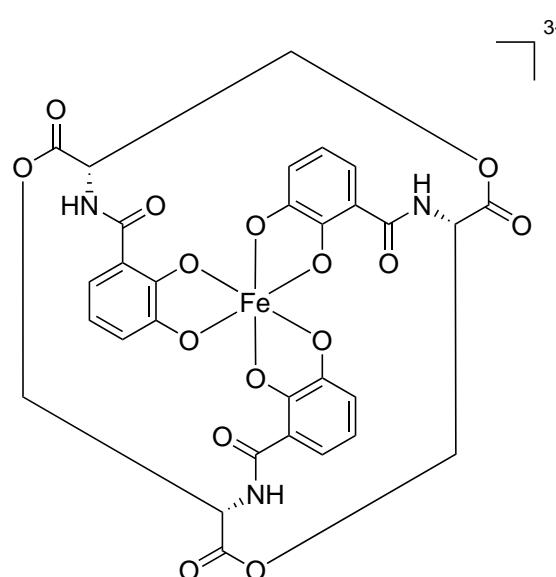
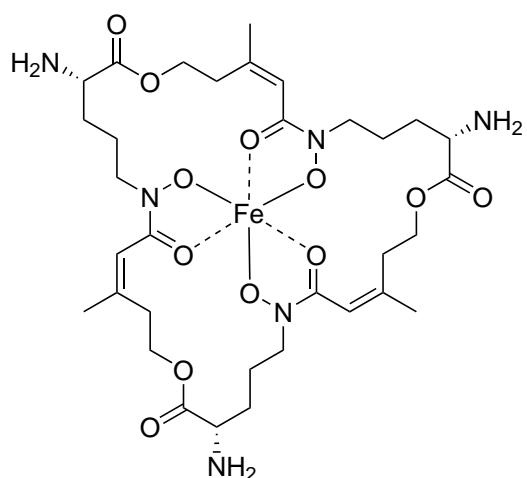
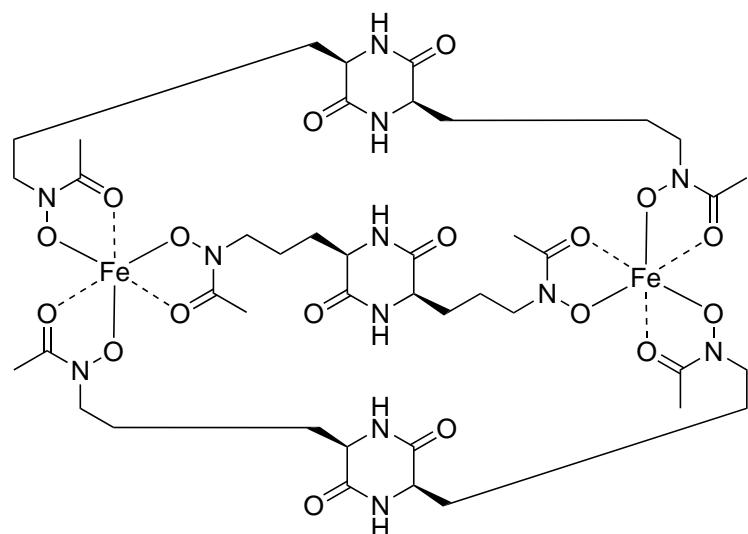
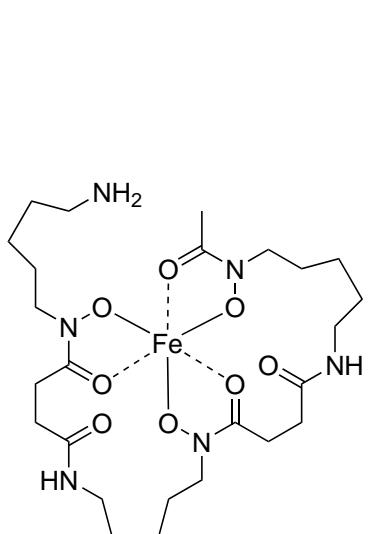


Figure 1: Iron-siderophore complexes: Deferoxamine B **1**³⁵ (*Streptomyces pilosus* and *Streptomyces coelicolor*), rhodotorulic acid **2**³⁶ (*Rhodotorula pilimanae*), fusarinine C **3**³⁷ (*Fusarium roseum*), enterobactin **4**³⁵ (*Escherichia coli* and enteric bacteria), ferrichrome **5**³⁸ (*Ustilago sphaerogenes*, *U. maydis*, *Aspergillus niger*, *A. quadricinctus*, *A. duricaulis* and *Penicillium resticulosum*), yersiniabactin **6**³⁵ (*Yersinia pestis*).

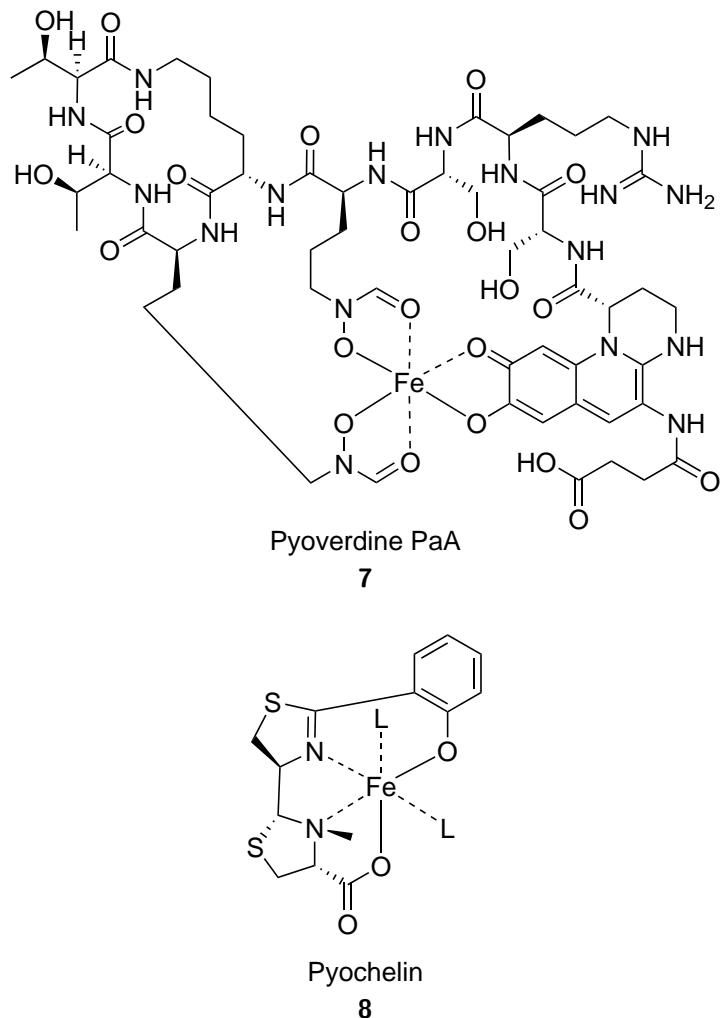


Figure 2: Iron-siderophore complexes: pyoverdine PaA **7**^{35,39} (*P. aeruginosa*, PAO1 strain) and pyochelin **8**^{40,41} (*P. aeruginosa*). Note that pyochelin **8** is a tetradeятate ligand, hence the iron ion has two sites which can bind other ligands.

5.2.2 Sideromycins

Siderophore-antibiotic conjugates are produced naturally by some bacteria and are known as sideromycins⁴ (see Figure 3). Bacteria produce these molecules to attack other bacteria by hijacking their siderophore uptake mechanisms to introduce toxic compounds.

For example, albomycin **9** (see Figure 3) is a sideromycin produced by *Actinomyces subtropicus* and *Streptomyces griseus*^{42,43} which has been used to treat infections caused by various bacteria including *Yersinia enterocolitica* and *Streptococcus pneumoniae* in mice and humans.^{44,45} Albomycin **9** contains a siderophore coupled to a nucleoside antibiotic via a peptide linker. The siderophore section is structurally similar to ferrichrome **5** (see Figure 1), a siderophore produced by various fungi, but also taken up by bacteria including *Escherichia coli*, *Salmonella typhimurium* and *P. aeruginosa*.^{38,46} It has been shown that because of the structural similarity to ferrichrome **5**, *E. coli* will also take up albomycin **9**.⁴² 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 albomycin⁴⁴ and other sideromycins such as salmycin A^{33,47,48} and ferrimycin A^{149,50} has served as encouragement to many researchers to explore synthetic siderophore-antibiotic conjugates, which will be discussed in the next section.

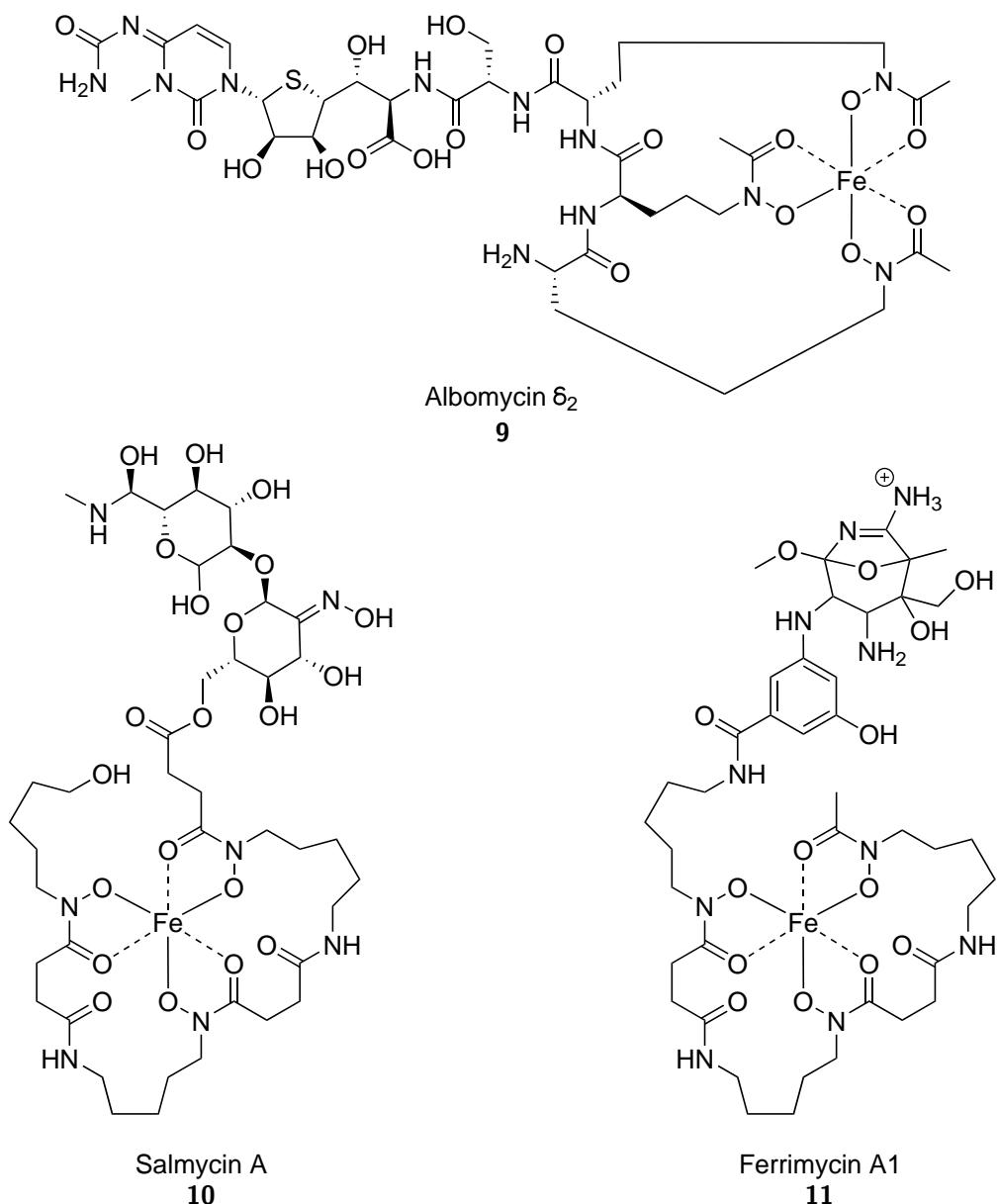


Figure 3: Iron-sideromycin complexes: Albomycin **9**^{33,51} (*Actinomyces subtropicus* and *Streptomyces griseus*), salmycin A^{33,47,48} (*Streptomyces violaceus*) and ferrimycin³³ (*Streptomyces griseoflavus*).

5.2.3 Synthetic siderophore-antibiotic conjugates

Sideromycins served as inspiration for the design, synthesis and biological evaluation of a wide range of synthetic siderophore-antibiotic conjugates.⁴ Antibiotics used include β -lactams,⁵²⁻⁵⁴ nucleosides,⁵⁵ glycopeptides⁵⁶ and macrolides.⁵⁷ Sideromycin-fluoroquinolone conjugates have also been studied by several groups,⁵⁸⁻⁶⁰ including conjugates with linkers which can be cleaved^{59,60} in a similar manner to albomycin.⁴² 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.⁴ Recently a conjugate (Ent-Amp **12**, see Figure 4) 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.⁶¹ Other

work has focused on monocyclic β -lactams, for example pirazmonam **13** and U-78608 **14**, which show high potency against Gram-negative bacteria including *P. aeruginosa*.^{62,63} 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:⁵ MC-1 **15**,⁶⁴ BAL30072 **16**⁴ (see Figure 4) and cefiderocol **17**^{65,66}.

MC-1 **15** is reported as being "in clinical phases of development",⁵ but no reports of studies in humans could be found. However, experiments in mice have been promising.⁶⁴ BAL30072 **16** 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.⁴ However, it is unclear whether it will progress further in trials as it causes liver toxicity.⁶⁷ Cefiderocol **17** 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'.⁶⁶

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 **9**-resistant mutants have been shown to be less virulent,⁴⁵ 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 virulence⁶⁸ with an antibiotic can be extended to conjugates of autoinducers and antibiotics in a similar 'Trojan horse' approach.

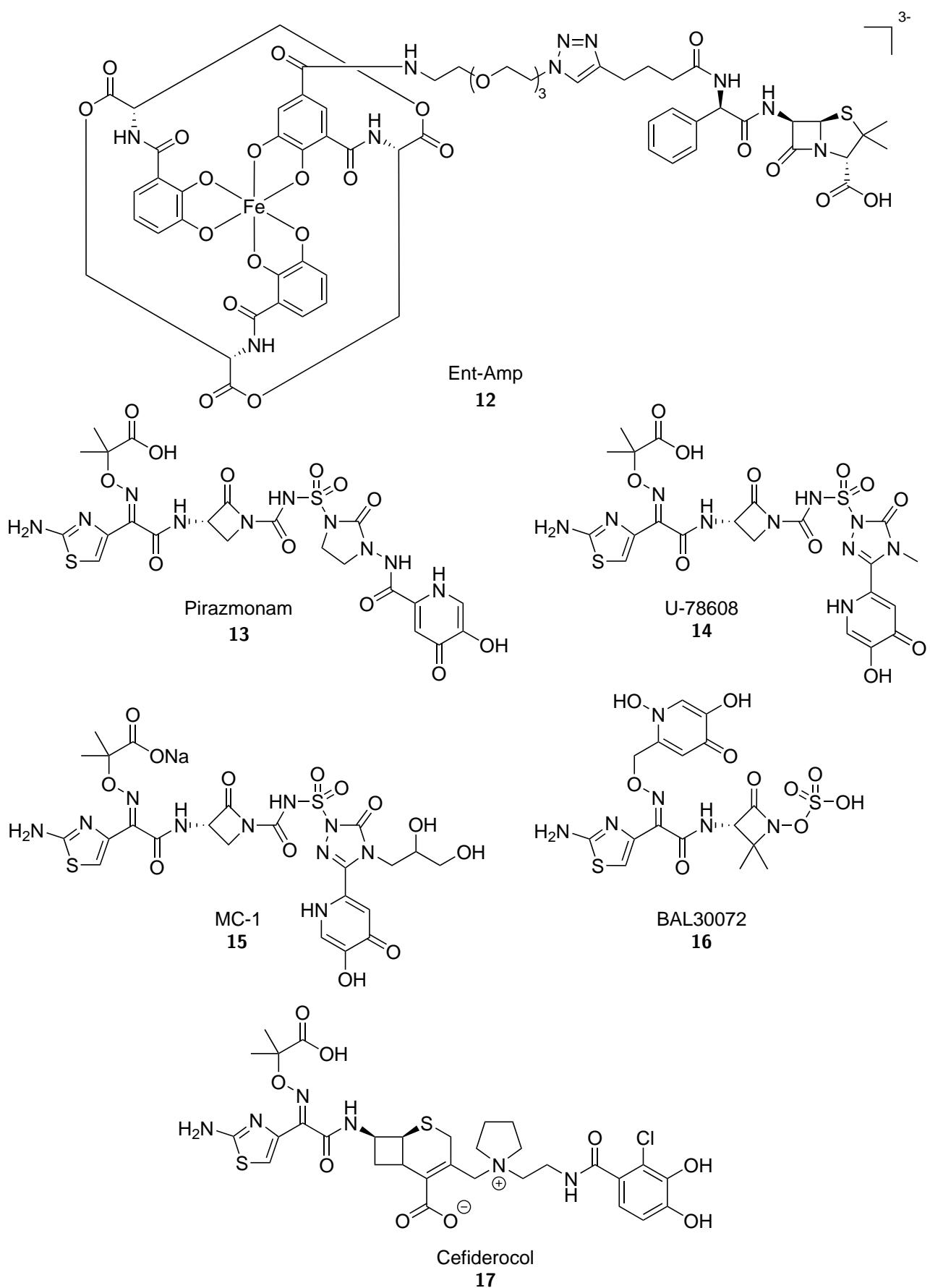


Figure 4: Examples of siderophore-antibiotic conjugates: Ent-Amp **12**,⁶¹ pirazmonam **13**,^{62,63} U-78608 **14**,^{62,63} MC-1 **15**,⁶⁴ BAL30072 **16**⁴ and cefiderocol **17**.^{65,66}

5.3 Autoinducer-antibiotic conjugates

This study extends 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. This section begins by introducing the concept of quorum sensing, followed by discussion of the autoinducers and antibiotics used in this study and the mechanisms of their efflux from *P. aeruginosa* cells, and how these mechanisms could be exploited by conjugates.

5.3.1 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'.⁶⁹ 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, swarming and biofilm formation.⁷ 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. 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.^{6,7,70-77} 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.¹

5.3.1.1 *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*^{7,76,77} (see Figure 5). This bacterium receives amino acids^{78,79} from its host in exchange for producing light which the squid uses for counterillumination, to camouflage itself.⁸⁰

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 5: ‘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 6).

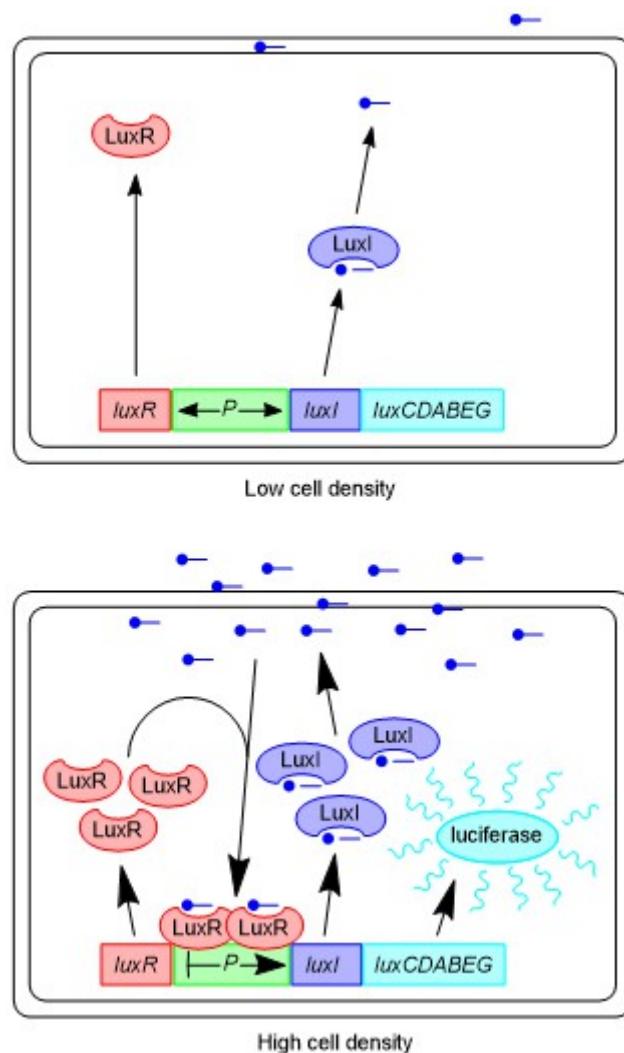


Figure 6: The LuxR-LuxI quorum sensing system in *V. fischeri*.

V. fischeri senses cell concentration by the detection of 3-oxo-C₆-HSL **18**⁸¹ (see Figure 7), a freely diffusible⁸²

better
quality
dia-
grams

molecule which is synthesised by LuxI^{83,84} and secreted by all *V. fischeri* cells⁸⁵ at a low basal level.⁷ When the bacterial population density, and hence the concentration of 3-oxo-C₆-HSL **18**, reaches a threshold, 3-oxo-C₆-HSL **18** binds to LuxR,^{86–88} a receptor which is also synthesised at a low basal level.

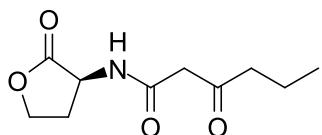


Figure 7: 3-oxo-C₆-HSL **18**.

The LuxR complex binds to the *lux* operator, upregulating production of LuxI and hence 3-oxo-C₆-HSL **18**, and luciferase enzymes and hence blue-green light.^{89–91} Production of more 3-oxo-C₆-HSL **18** enables a positive feedback loop, reinforcing the effect of high population density on 3-oxo-C₆-HSL **18** concentration and hence light production. This is the reason that 3-oxo-C₆-HSL **18** 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 **18** production of LuxR is inhibited.⁹² Such balancing effects, as well as interactions with other quorum sensing and metabolic systems, are very common.

5.3.1.2 *Pseudomonas aeruginosa*

Another well-studied example of quorum sensing is in *P. aeruginosa*.^{12,93,94} *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.¹⁰ Multidrug-resistant *P. aeruginosa* is classified as a ‘serious threat’ by the United States Centers for Disease Control and Prevention¹ and carbapenem-resistant *P. aeruginosa* is classified as ‘priority 1: critical’ by the World Health Organisation.²⁸

P. aeruginosa has a low susceptibility to many antibiotics and readily acquires antibiotic resistance by mutation or horizontal gene transfer.⁹⁵ It is difficult for antibiotics to cross into cells due to low cell membrane permeability⁹⁶ and biofilm formation,⁹⁷ and they are pumped out again by its multiple chromosomally encoded multidrug efflux pumps.¹¹ *P. aeruginosa* biofilms are more resistant to many drugs including ciprofloxacin **24** and trimethoprim **25** compared with planktonic cells.^{97,98} 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 8) and various proteins (see Figure 9).^{12,93,94} These can be broken down into three main, interacting systems: Las, Rhl and Pqs.

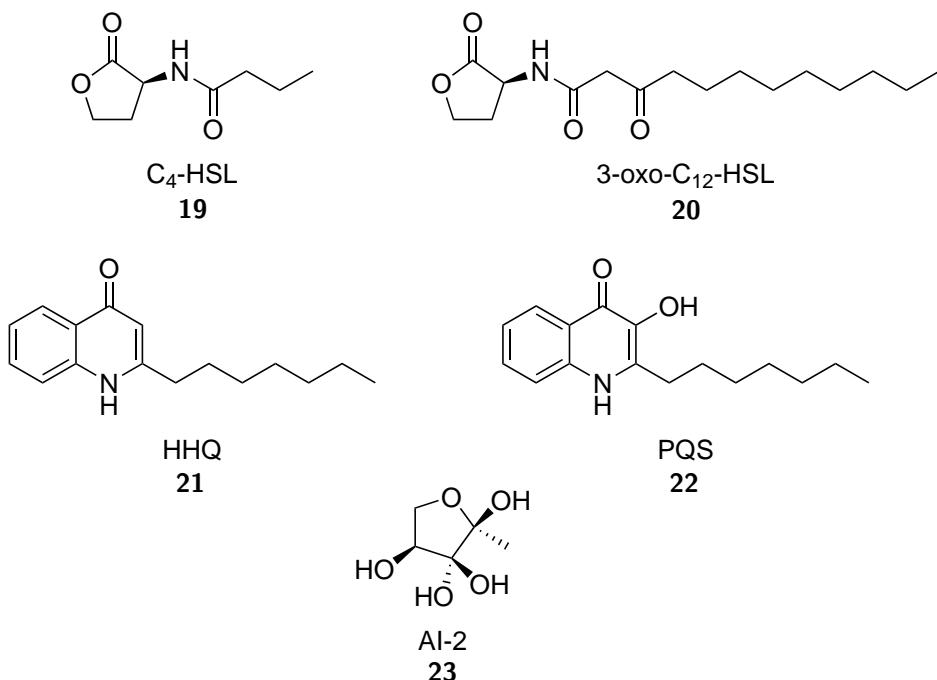


Figure 8: *P. aeruginosa* autoinducers.

In the Las system, LasI⁹⁹ synthesises the 3-oxo-C₁₂-HSL **20**¹⁰⁰ autoinducer. 3-oxo-C₁₂-HSL **20** binds LasR,¹⁰¹ and this complex upregulates the production of LasI¹⁰² (thus causing autoinduction) as well as alkaline protease,¹⁰³ elastase,¹⁰¹ exotoxin A,¹⁰³ HCN¹⁰⁴ and LasA protease.¹⁰⁵ The LasR complex is also important in late-stage biofilm formation,⁷³ and upregulates the Rhl¹⁰⁶ and Pqs systems.^{107,108}

In the Rhl system, RhlI¹⁰⁹ synthesises the C₄-HSL **19**¹¹⁰ autoinducer. C₄-HSL **19** binds RhlR,¹¹¹ and this complex upregulates the production of RhlI¹⁰² (again causing autoinduction), alkaline protease,¹¹² elastase,¹⁰⁹ haemolysin,¹¹² HCN,^{104,112} LasA protease,¹⁰⁹ LecA,¹¹³ pyocyanin^{109,112} and rhamnolipids.¹⁰⁹ The RhlR complex also downregulates the Pqs system.^{108,114} The Rhl system is controlled by both the Las and Pqs systems, as production of both RhlR and RhlI is upregulated by the LasR complex¹⁰⁶ and production of both RhlR is upregulated by the PqsR complex.¹¹⁵

In the Pqs system, the main autoinducer, PQS **22**,¹¹⁶ is synthesised by multiple enzymes. PhnAB,¹¹⁷ PqsA, PqsBC, PqsD^{118,119} and PqsE^{120,121} produce the precursor HHQ **21**, and PqsH converts HHQ **21** to PQS **22**. PQS **22**¹⁰⁸ or HHQ **21** binds PqsR,¹²² and either complex can upregulate the synthesis of HHQ **21** causing autoinduction. The PqsR-PQS complex upregulates the production of chitinase,¹²³ elastase,¹¹⁶ HCN,¹²³ LecA,¹²⁴ pyocyanin^{107,125} and pyoverdine,¹²⁵ as well as increasing biofilm production¹²⁴ and vesicle formation.¹²⁶ The PqsR-PQS complex also upregulates production of RhlR, so the Pqs system has control over the Rhl system.¹¹⁵ The Pqs system is controlled by both the Las and Rhl systems, as production of PqsR¹⁰⁸ and PqsH¹⁰⁷ is upregulated by the LasR complex and production of PqsA, PqsBC, PqsD, PqsE¹¹⁴ and PqsR¹⁰⁸ is downregulated by the RhlR complex.

add
numbers
man-
ually
when
sorted

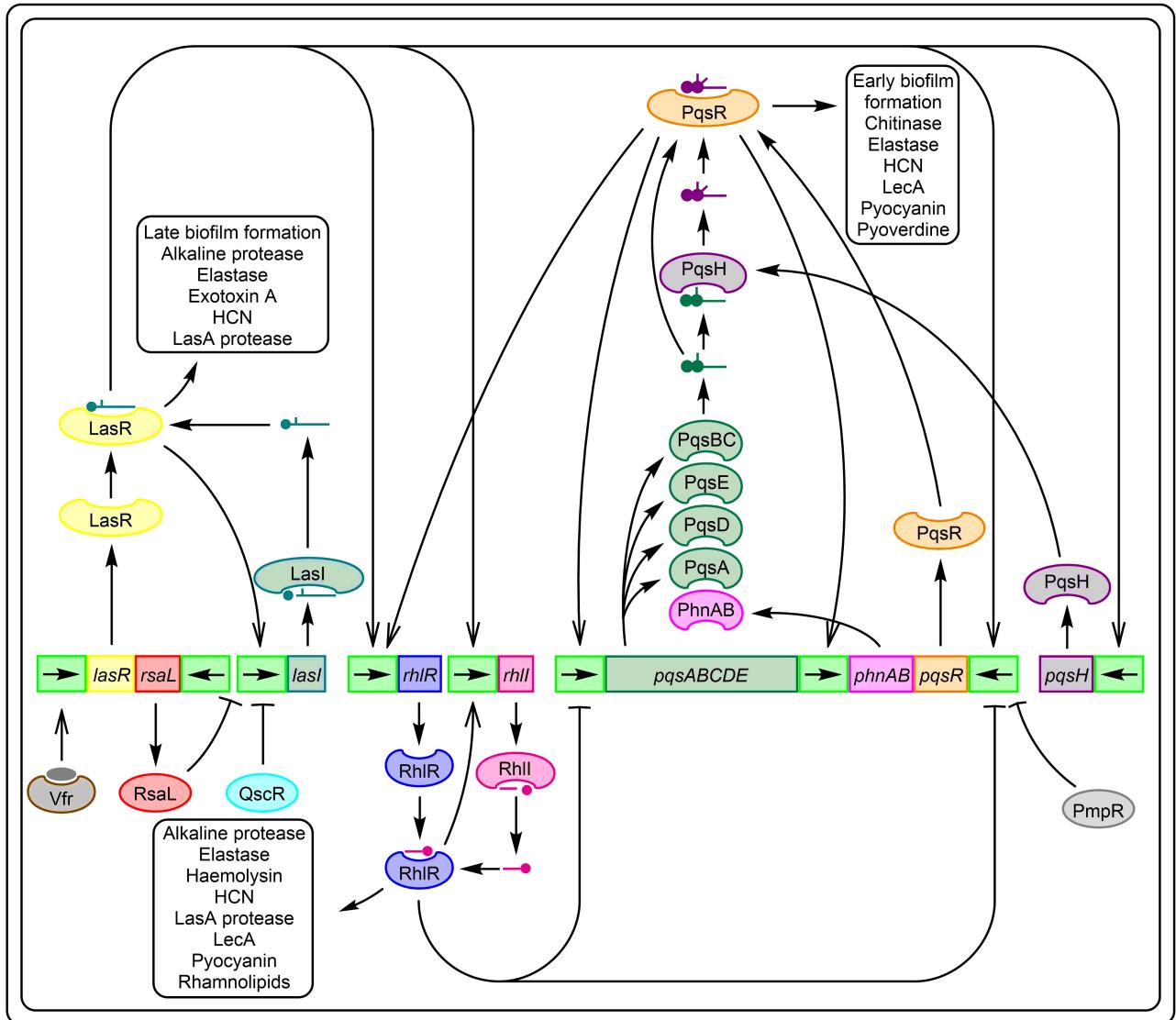
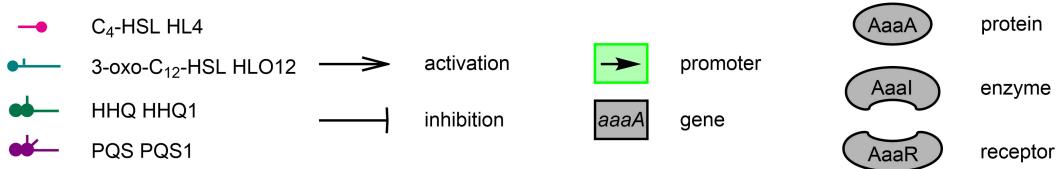


Figure 9: Quorum sensing in *P. aeruginosa*.^{12, 93, 94}

In addition to the above systems, AI-2 (see Figure 8), an interspecies signalling molecule,¹²⁷ is known to increase biofilm production and virulence in *P. aeruginosa*.^{128, 129} 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 8 as part of three interacting quorum sensing systems to coordinate virulence and biofilm production, and this makes these autoinducers interesting therapeutic targets.

5.3.2 Autoinducers

Quorum sensing has been successfully targeted using many different modulators,^{93, 130} but this study takes a slightly different approach. Inspired by the success of various siderophore-antibiotic conjugates (see 5.2.3), 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 5.3).

The *P. aeruginosa* autoinducers (see Figure 8) were chosen for use in this study as *P. aeruginosa* is a significant human pathogen which shows high antibiotic resistance and utilises quorum sensing to coordinate pathogenic behaviours (see 5.3.1.2). Specifically, C₄-HSL **19**, HHQ **21** and PQS **22** derivatives were chosen as they were considered to be the most synthetically tractable.

5.3.3 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 **21** or AI-2 **23**, but it is known that PQS **22** is exported in vesicles,¹³¹ C₄-HSL **19** passively diffuses in and out of cells,¹³² and 3-oxo-C₁₂-HSL **20** 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 **19** and 3-oxo-C₁₂-HSL **20** is thought to be largely due to chain length rather than the 3-oxo modification, as a shorter-chain version, 3-oxo-C₆-HSL **18** has been shown to be freely diffusible through *V. fischeri* membranes.⁸²

3-oxo-C₁₂-HSL **20** is exported primarily via the MexAB-OprM efflux system.^{11,133} The increased removal of 3-oxo-C₁₂-HSL **20** from the cell by upregulation of the MexAB-OprM system leads to decreased production of additional 3-oxo-C₁₂-HSL **20** (as the positive feedback loop is disrupted, see 5.3.1.2), 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 **20** levels would disrupt Las-mediated quorum sensing,¹³⁴ but no direct studies of this could be found.

5.3.4 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*.^{13,135} Ciprofloxacin **24** inhibits DNA replication by binding to DNA gyrase and topoisomerase IV.¹³⁶

Trimethoprim (see Figure 10) is a dihydrofolate reductase inhibitor used primarily to treat bladder infections.¹³⁷ 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*.

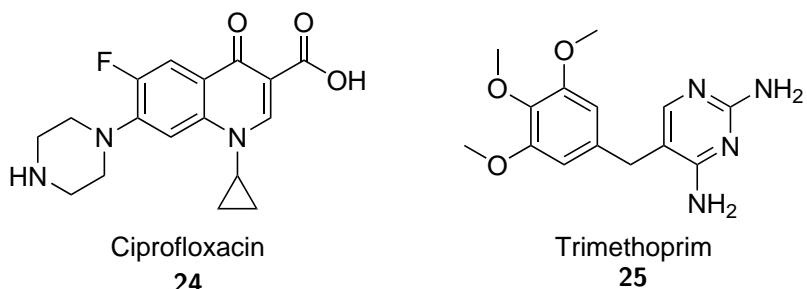


Figure 10: The antibiotics used in this section.

5.3.5 Antibiotic efflux

Ciprofloxacin **24** enters *P. aeruginosa* by diffusion,¹³⁸ but is pumped out by efflux pumps.¹³⁹ 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.¹¹ However, in biofilms only MexEF–OprN has an effect.¹⁴⁰

Trimethoprim **25** is mainly exported by the MexAB–OprM,¹⁴¹ MexCD–OprJ¹⁴² and MexEF–OprN¹⁴³ multidrug efflux systems^{11,144} 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.⁹⁸

5.3.6 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.^{12,133,134} 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 **20**.^{11,133} For PQS conjugates this would mean upregulation of vesicle formation.¹³¹
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 biofilms¹⁴⁰ and not an exporter of HSLs **19** or **20**, or PQS **22**¹¹). 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.

5.3.7 HSL 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 paper¹⁴⁵ and patent¹⁴⁶ by Ganguly *et al.*, who synthesised and characterised a conjugate **101** 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.^{85,147–153}

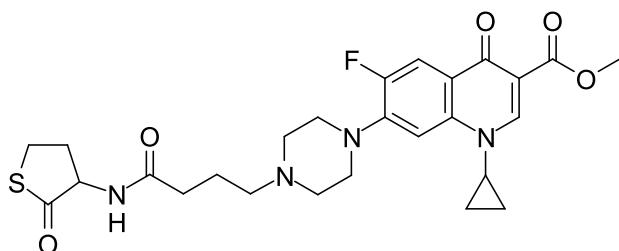


Figure 11: The HCTL-CipMe conjugate **101** studied by Ganguly *et al.*^{145,146}

As part of their characterisation of the HCTL-CipMe conjugate **101**, 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 **101**. They then incubated cultures for 24 h, to allow biofilms to grow, before adding the compounds. In contrast, they found that the conjugate **101** 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 **19**.

It is possible that the conjugate **101** has higher activity against biofilms when compared with ciprofloxacin **24** because conjugate **101** 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 5.3.6).

While one might expect the conjugate **101** to behave like C₄-HSL **19**, and hence passively diffuse in and out of cells, it is possible that its transport more closely resembles that of 3-oxo-C₁₂-HSL **20**. 3-oxo-C₁₂-HSL **20**’s accumulation in membranes and interaction with efflux pumps is thought to be based primarily on tail chain length (see 5.3.3), and the ciprofloxacin half of the conjugate **101** could be seen as a long tail, especially as the carboxylic acid is methylated and hence less polar.

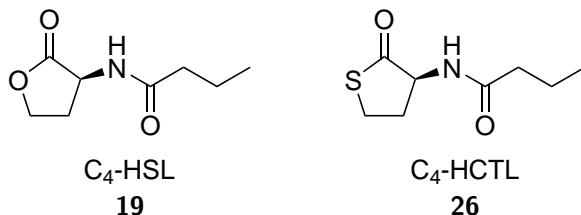


Figure 12: C₄-HSL **19** and C₄-HCTL **26**. Note that Ganguly *et al.* tested the *S* enantiomer of C₄-HCTL **26**, but used a racemic mixture in their HCTL-CipMe conjugate.

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.^{130, 154}

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 ??.

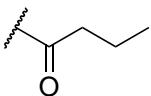
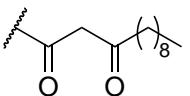
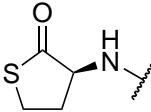
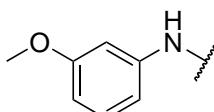
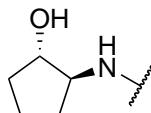
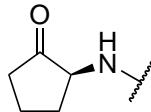
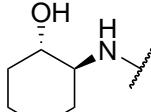
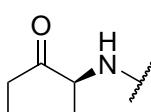
Head group		
	Partial agonist and antagonist against LasR. ¹⁵¹ Shown to increase biofilm formation in <i>P. aeruginosa</i> . ¹⁴⁵	Strong agonist against LasR, with comparable activity to the native ligand. ^{148, 149, 151, 155}
	Partial agonist against LasR. ¹⁵⁴	Strong antagonist against LasR. ¹⁵⁴
	Poor agonist and antagonist against RhlR. ^{156, 157}	Strong antagonist against LasR. ¹⁵⁶
	Strong agonist against RhlR. ¹⁵⁶ SS enantiomer is more potent. ¹⁵⁷	Partial agonist against LasR. ¹⁵⁶
	Strong agonist against RhlR. ¹⁵⁶ SS enantiomer is more potent, with comparable activity to the native ligand. ¹⁵⁷	Strong agonist against LasR. ^{149, 156} SS enantiomer is more potent, with comparable activity to the native ligand. ¹⁵⁷
	Strong agonist against RhlR. ¹⁵⁶ SS enantiomer is more potent. ¹⁵⁷	Partial antagonist against LasR. ¹⁵⁶ Shown to reduce biofilm formation in <i>P. aeruginosa</i> . ¹⁵⁶

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

6 Project aims and summary

The aim of this project is to produce and test a library of autoinducer-antibiotic conjugates with the hope of producing conjugates with greater potency than the parent antibiotics. The work is divided into two main sections. Section 7 focuses on conjugates of three *P. aeruginosa* autoinducers (see Figure 8) with ciprofloxacin and trimethoprim (see Figure 10) joined using a copper(I)-catalyzed azide-alkyne cycloaddition. Section 8 focuses on conjugates of homoserine lactone analogues with ciprofloxacin (see 5.3.7) joined either using a copper(I)-catalyzed azide-alkyne cycloaddition or an S_N2 reaction or peptide coupling.

7 Results and discussion: autoinducer-antibiotic conjugates

7.1 Overview

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 **19**, HHQ **21** and PQS **22** (see Figure 8). 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.^{8,9}

7.1.1 Azido autoinducer derivatives

The structure-activity relationships in HHQ **21** and PQS **22** have been previously studied,^{158–160} 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.¹⁶¹

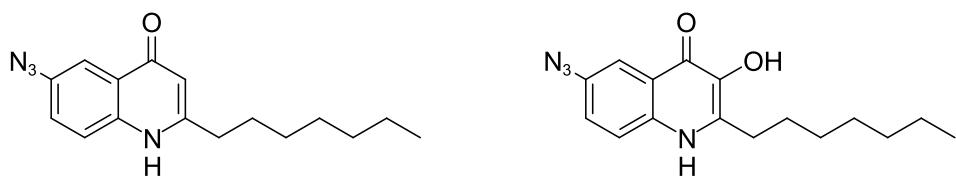


Figure 13: The azido derivatives of HHQ **21** and PQS **22**: **36** and **47**.

Alteration of the lactone group of HSL derivatives is known to significantly decrease activity, especially where the number of H-bond donors or acceptors is altered.¹³⁰ Hence, the azide group was included on the tail.¹⁶² Acyl tail length is known to play an important role in affinity,¹³⁰ so three derivatives of C₄-HSL **19** were synthesised: N₃-C₂-HSL **53**, N₃-C₄-HSL **56** and N₃-C₆-HSL **59** (see Figure 14).

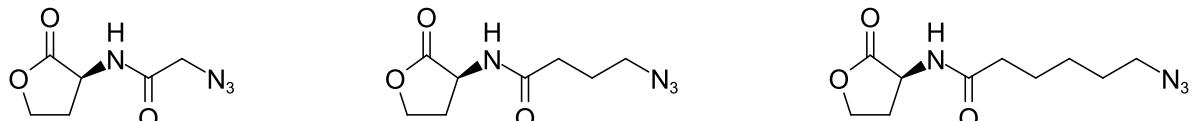


Figure 14: The azido derivatives of C₄-HSL **19**: **53**, **56** and **59**.

7.1.2 Alkynyl antibiotic derivatives

The structure-activity relationships for ciprofloxacin have been investigated¹⁶³ 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 **66** (see Figure 15) was synthesised in this study (see 7.3.1), and two cleavable alkynyl ciprofloxacin derivatives **88** and **89** were synthesised by Dr Eddy Sotelo and combined with some of the azido HSL derivatives made in this study (see 7.2.3 and 7.4.3).

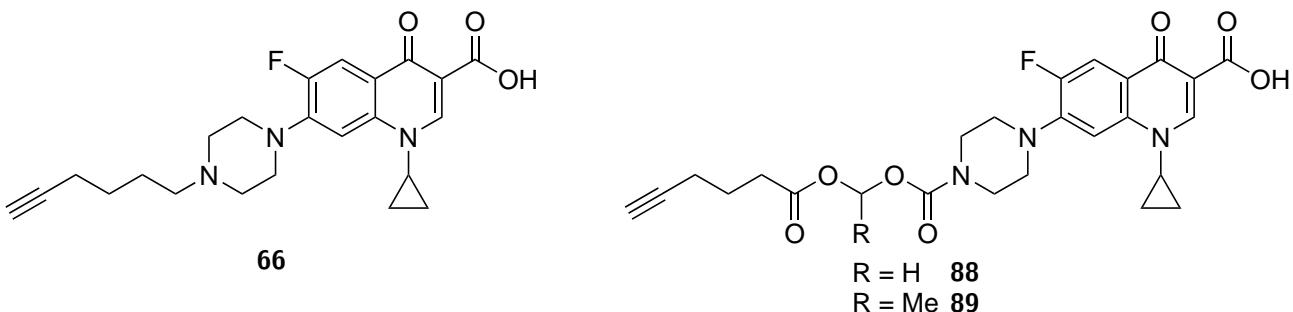


Figure 15: The alkynyl ciprofloxacin derivatives **66**, **88** and **89**.

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.*¹⁶⁴

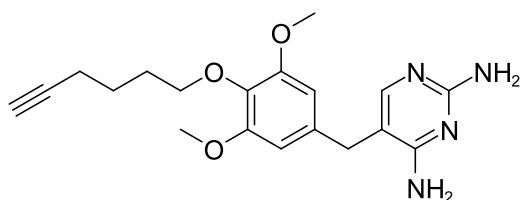
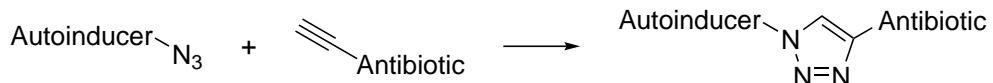


Figure 16: The alkynyl trimethoprim derivative **69**.

7.1.3 Synthesis of the conjugates

A copper(I)-catalysed azide-alkyne cycloaddition,^{8,9} 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).



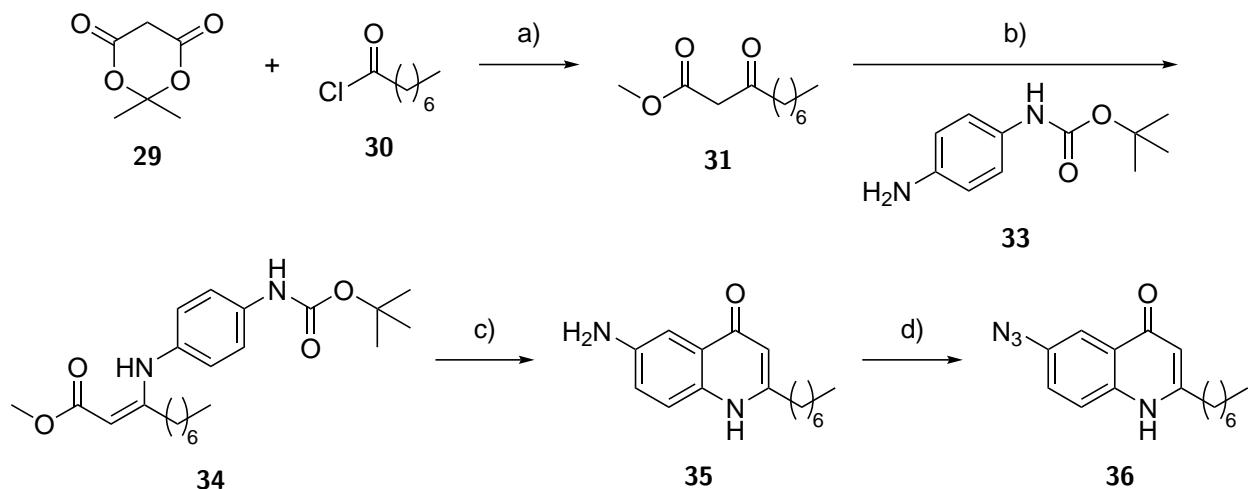
Scheme 1: The construction of the triazole-linked autoinducer-antibiotic conjugate library using a copper(I)-catalysed azide-alkyne cycloaddition.

7.2 Azido autoinducer derivatives

7.2.1 Synthesis of 6-N₃-HHQ **36**

The synthesis of 6-N₃-HHQ **36** is shown in Scheme 2 and follows a route devised by Baker.¹⁶¹ Octanoyl chloride **30** was converted to β -ketoester **31** via a Meldrum's acid adduct.^{165,166} The β -ketoester **31** was condensed with *N*-Boc-*para*-phenylenediamine **33** to form enamine **34**. 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 **34** was cyclised with polyphosphoric acid to form amino-HHQ **35** in good yield. The amine group of amino-HHQ **35** was converted to a diazo group by reaction with NaNO₂ and HCl, followed by displacement with NaN₃ to form the final azido-HHQ product **36**.¹⁶⁷



Scheme 2: The synthesis of **36**. a) i) Pyridine, CH_2Cl_2 , $0\text{ }^\circ\text{C}$. ii) MeOH , reflux, 66 % over two steps. b) MeOH , reflux, 19 %. c) Polyphosphoric acid, $120\text{ }^\circ\text{C}$, 72 %. d) i) NaNO_2 , HCl , H_2O , $0\text{ }^\circ\text{C}$. ii) NaN_3 , H_2O , r.t., 46.5 %.

7.2.2 Synthesis of 6-N₃-PQS **47**

The synthesis of 6-N₃-PQS **47** is shown in Scheme 3, and also follows a route devised by Baker.¹⁶¹ The Weinreb amide **41**⁹³ was prepared from chloroacetyl chloride, followed by attack with heptyl magnesium bromide **38** to form 1-chlorononan-2-one **42** following a procedure described by Hodgkinson *et al.*¹⁶⁸

The synthesis of PQS **22** described by Hodgkinson *et al.*¹⁶⁸ used a microwave reaction of 1-chlorononan-2-one **42** with anthranilic acid. It was hoped that the azide group could be installed by using 5-nitroanthranilic acid **43** 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 **43** was used.¹⁶¹ Therefore, a two step process was employed instead.

5-Nitroanthranilic acid **43** was heated with K_2CO_3 to deprotonate the carboxylic acid, followed by addition of 1-chlorononan-2-one **42** to form the ester **44** by $\text{S}_{\text{N}}2$ displacement of the chlorine atom in a procedure adapted from Hlaváč *et al.*¹⁶⁹ Cyclisation with polyphosphoric acid produced nitro-PQS **45** cleanly.^{169, 170}

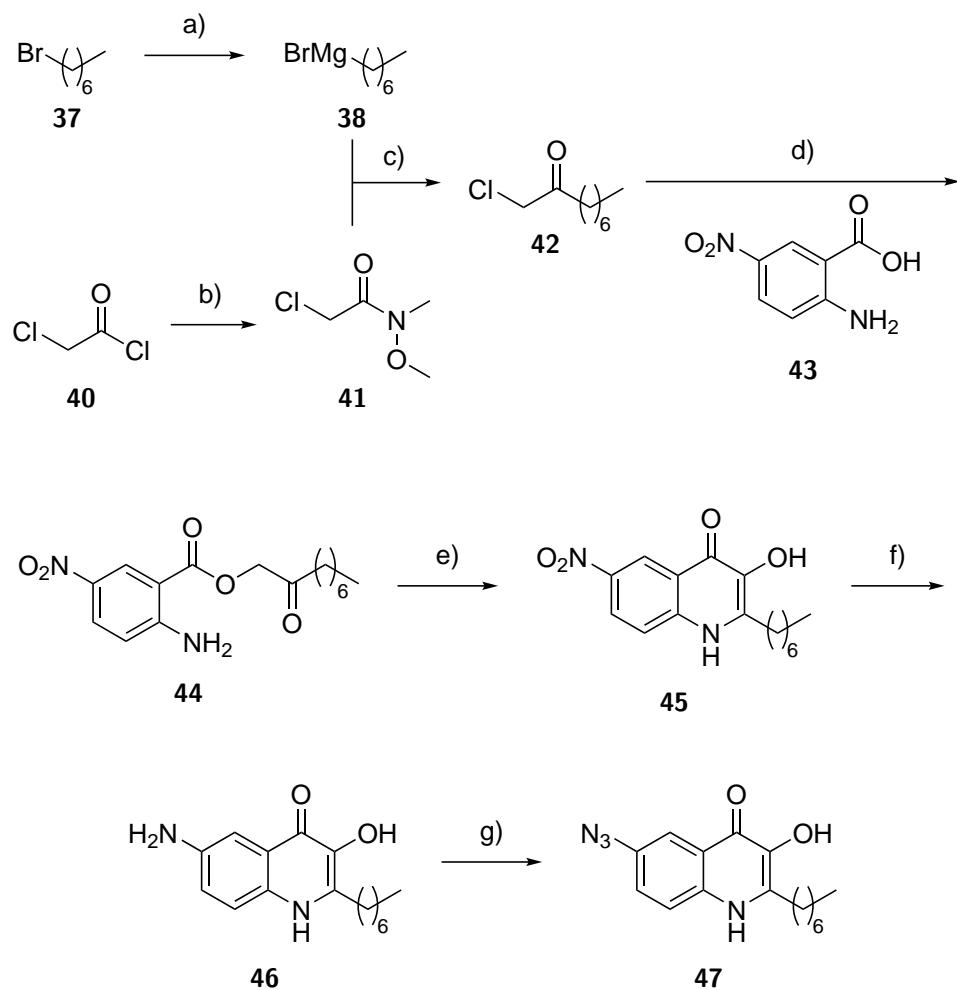
Conditions for the reduction of the nitro group were then compared (see Table 3). Baker initially used Zn and HCl, however this gave a yield over 100 % suggesting coordination of Zn to the amino-PQS **46**¹⁶¹ (this product was taken through and purified after the next step). She also attempted reduction with Pd/C and H_2 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 **46**. An initial test of reduction with SnCl_2 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 H_2 . Good yields (80 %) were also achieved using PtO_2 as a catalyst, with the advantage that the reaction proceeds more quickly, and at atmospheric pressure and temperature.¹⁷¹

Finally, amino-PQS **46** was converted to azido-PQS **47** by reaction with NaNO_2 and HCl to form diazo-PQS, followed by displacement of the diazo group using NaN_3 to give the azido-PQS **47**.¹⁶⁷ The yield of this reaction was rather disappointing (28 %), and is probably due to loss of product in the supernatant following precipitation.¹⁶¹

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 46 + 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 46 , 100 % yield
H_2 , PtO_2 , MeOH, 1 atm, r.t., 45 min	Product 46 , 80 % yield

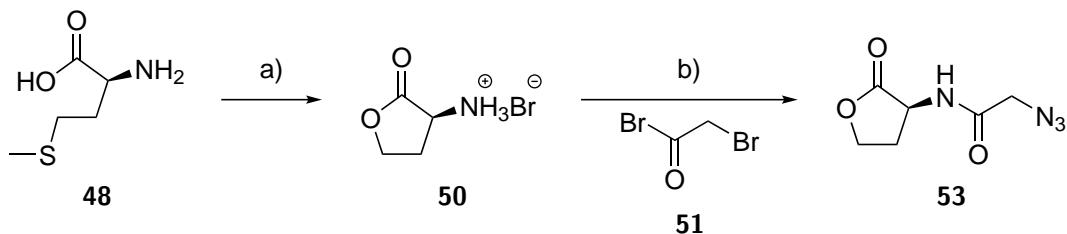
Table 3: Conditions attempted for the synthesis of **46**. Rows 1-3 were carried out by Baker,¹⁶¹ rows 4-6 were carried out as part of this study.



Scheme 3: The synthesis of **47**. 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) **43**, K_2CO_3 , DMF, 90 °C, 1 h, then **42**, 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.

7.2.3 Synthesis of the azido C₄-HSL derivatives **53**, **56** and **59**

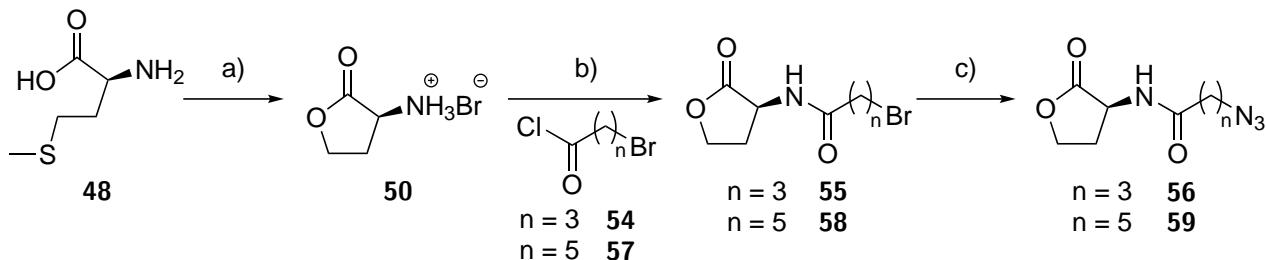
N₃-C₂-HSL **53** (the azido derivative of C₄-HSL with a C₂ chain, see Scheme 4) has previously been prepared by Stacy *et al.*¹⁶² Their synthesis was followed, starting with the cyclisation of L-methionine **48** using bromoacetic acid to form the homoserine lactone HBr salt **50**. The disappointing yield can be attributed to difficulties in precipitating the final product. The homoserine lactone HBr salt **50** was then converted by a biphasic one-pot process to N₃-C₂-HSL **53** using bromoacetyl bromide **51** and NaN₃.



Scheme 4: The synthesis of **53**. 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 **48** to N₃-C₄-HSL **56** using 4-bromobutyryl chloride **54** 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 **50** with 4-bromobutyryl chloride **54** or 6-bromohexanoyl chloride **57** produced Br-C₄-HSL **55** or Br-C₆-HSL **58** respectively, in good yields. Heating with NaN₃ in DMF converted Br-C₆-HSL **58** to N₃-C₆-HSL **59**. Similar conditions were used by Dr. Bin Yu, a visiting PhD student in the Spring group, to convert the bromo-C₄ derivative **55** to the azido-C₄ derivative **56**, 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 **56** and **59**. a) Bromoacetic acid, *i*-PrOH:H₂O:AcOH (5:5:2), r.t, 18 h, 41 %. b) NaHCO₃, H₂O/CH₂Cl₂, r.t., 18 h, **55**: 80 %, **58**: 66 %. c) NaN₃, DMF, 100 °C, 5 h, **59**: 27 % (donated by Dr. Bin Yu), **59**: 56 %.

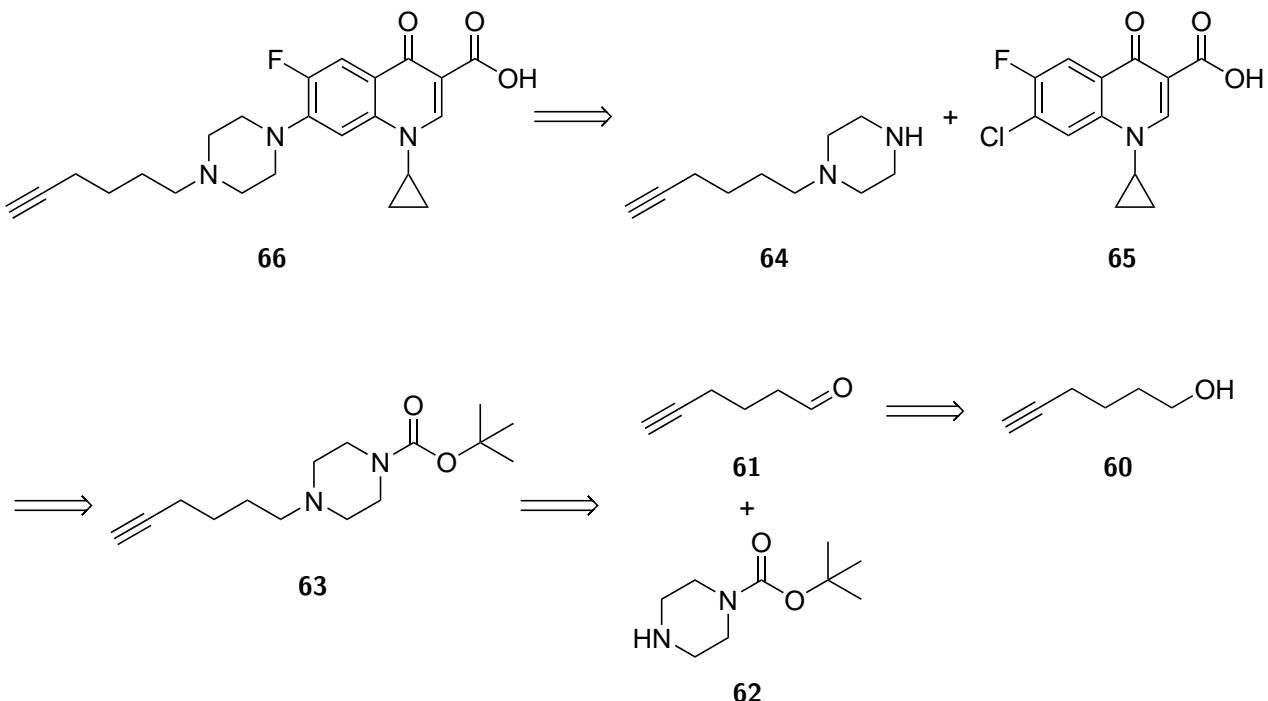
7.3 Alkynyl antibiotic derivatives

7.3.1 Synthesis of the alkynyl ciprofloxacin derivative **66**

The retrosynthesis of ciprofloxacin derivative **66** is shown in Scheme 6. The disconnection to an alkynyl piperazine **66** and a commercially available ciprofloxacin precursor **65** 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."^{163,172}

It was envisaged that the alkynyl piperazine **66** could be prepared from mono-Boc-protected piperazine **62** and hex-5-ynal **61** using conditions similar to those used by Renau *et al.*¹⁶³

Unlike the aldehydes and ketones used by Renau *et al.*,¹⁶³ hex-5-ynal **61** is not commercially available and so it was hoped that this could be prepared by oxidation of hex-5-ynol **60**.



Scheme 6: The retrosynthesis of **66**.

The synthesis of ciprofloxacin derivative **66** is shown in Scheme 7. Hex-5-ynal **61** was prepared by pyridinium chlorochromate oxidation of hex-5-ynol **60** in good yield according to the procedure described by Kocsis *et al.*¹⁷³

Renau *et al.*¹⁶³ used sodium cyanoborohydride to facilitate the reductive amination of hex-5-ynal **61** and 1-Boc-piperazine **62**. However, it was decided to attempt this transformation using the less toxic sodium triacetoxyborohydride following a procedure reported by Abdel-Magid *et al.*¹⁷⁴ This reaction yielded compound **63** in excellent yield, which was deprotected using TFA using the procedure described by Renau *et al.*¹⁶³ to give the alkynyl piperazine **64** quantitatively.

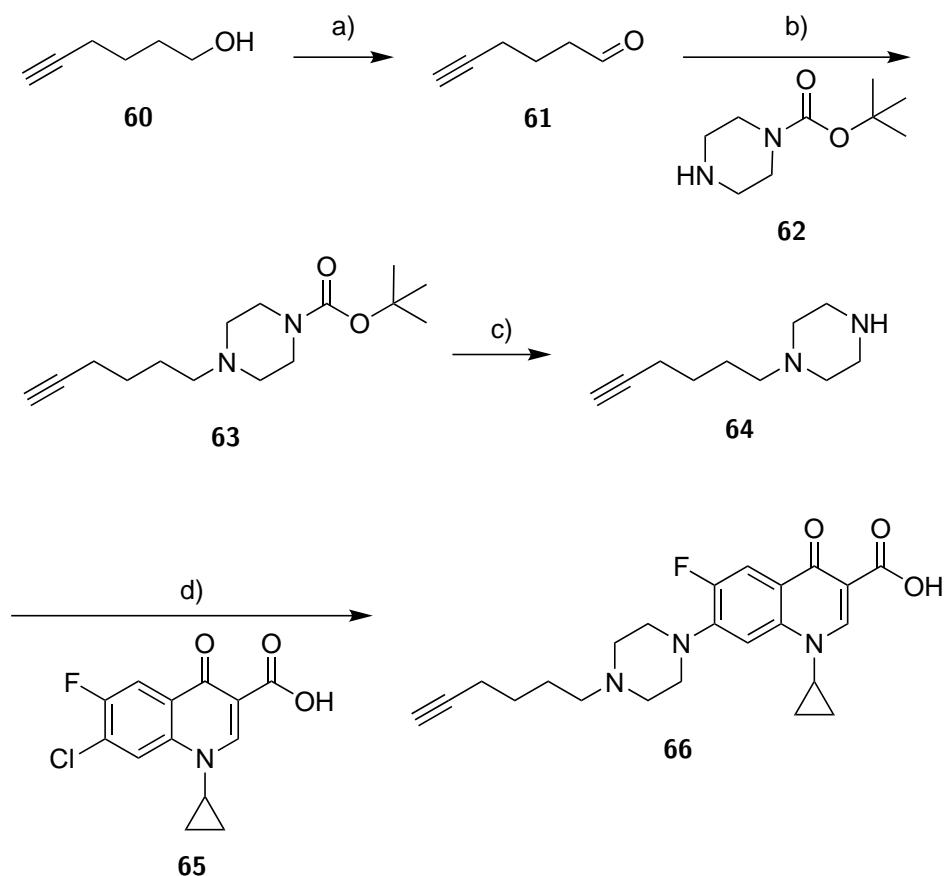
The alkynyl piperazine **64** was refluxed in acetonitrile with the ciprofloxacin precursor **65** according to the procedure described by Renau *et al.*,¹⁶³ however the reaction did not proceed. Addition of 2 eq. of TEA did not lead to reaction, however it was found that refluxing in neat TEA led to conversion to the final ciprofloxacin derivative **66**.

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.*¹⁷⁵ 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 challenging, 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 poor (11.8 %). The reaction was observed to stall after a certain point, while still having some of the ciprofloxacin precursor **65** present. The alkynyl piperazine **64** 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 **64** 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.



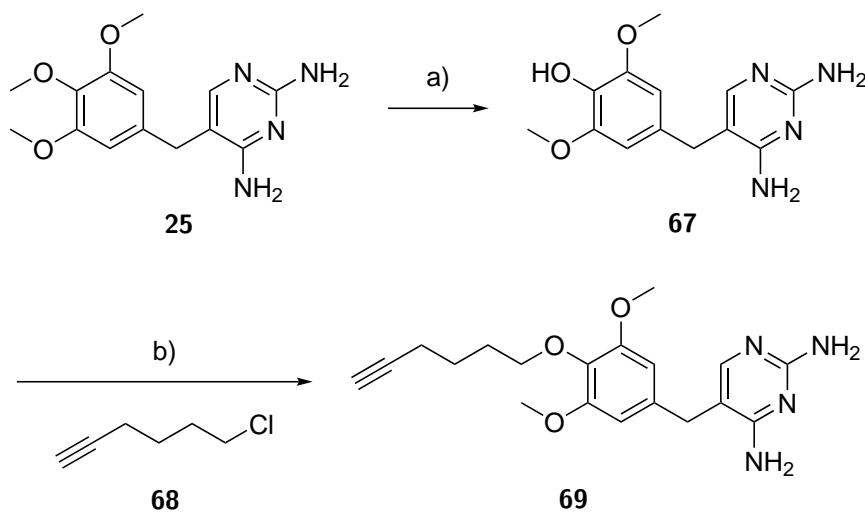
Scheme 7: The synthesis of **66**. a) Pyridinium chlorochromate, CH_2Cl_2 , r.t., 5 h, 72 %. b) $\text{NaBH}(\text{AcO})_3$, 1,2-dichloroethane, r.t., 10.5 h, 99 %. c) TFA, r.t., 1 h, 100 %. d) NMP, microwave, 115 °C 24 h, 11.8 %.

7.3.2 Synthesis of the alkynyl trimethoprim derivative **69**

The synthesis of trimethoprim derivative **69** is shown in Scheme 8. Trimethoprim was selectively deprotected using HBr (aq.) using a procedure described by Jing *et al.*¹⁶⁴ to form **67**. A slightly longer reaction time (40 min vs 20 min) probably led to the yield being 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 **69** was synthesised from the demethylated trimethoprim **67** and 6-chloro-1-hexyne **68** 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 **69**. a) HBr (aq.), 100 °C, 40 min, 43.4 %. b) Cs₂CO₃, DMF, 70 °C, 7 h, 19.6 %.

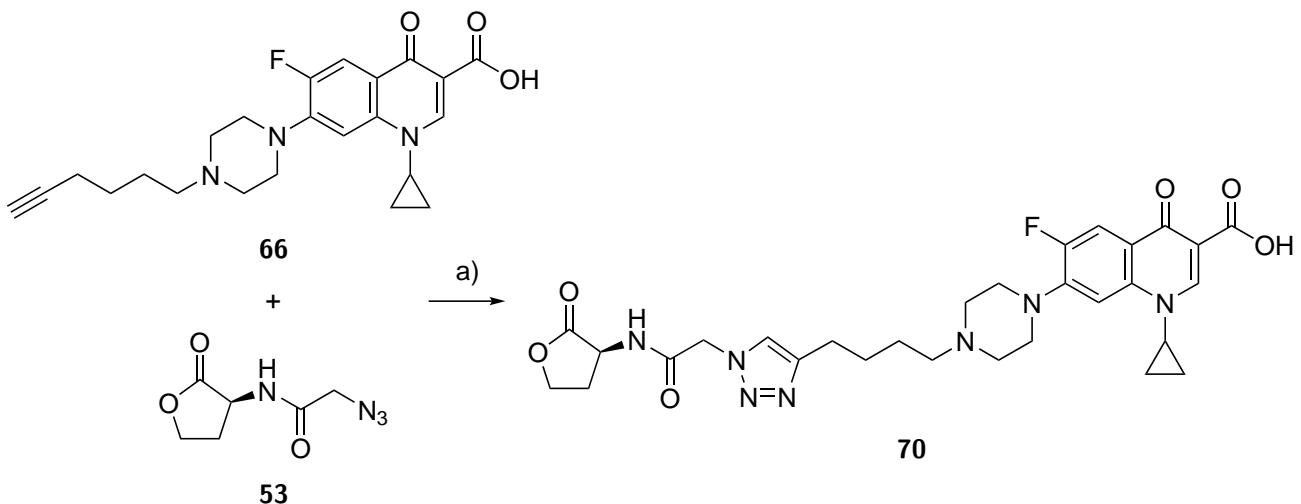
7.4 Triazole-linked autoinducer-antibiotic conjugates

7.4.1 Optimisation of the click reaction

Test reactions using N₃-C₂-HSL **53** and the alkynyl ciprofloxacin derivative **66** 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 **70** and 1,5 **71** isomers was observed in an approximately 4:1 ratio by LCMS (see Figure 18). Use of the ligand tris(3-hydroxypropyltriazolylmethyl)amine (THPTA) **72** (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 70 and 1,5 triazole impurity 71 4:1
CuSO ₄ ·H ₂ O, sodium ascorbate, THPTA 72 , H ₂ O, <i>t</i> -BuOH, air, r.t., 3 h.	1,3-Triazole product 70 and starting materials 53 and 66
CuSO ₄ ·H ₂ O, sodium ascorbate, THPTA 72 , H ₂ O, <i>t</i> -BuOH, Ar, r.t., 3 h.	1,3-Triazole product 70

Table 4: Conditions attempted for the synthesis of **70** (see Scheme 9).



Scheme 9: Synthesis of **70**. For conditions see Table 4.

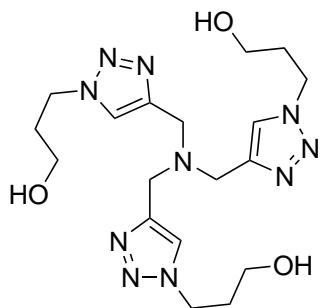


Figure 17: Tris[(1-benzyl-1*H*-1,2,3-triazol-4-yl)methyl]amine (THPTA) **72**.

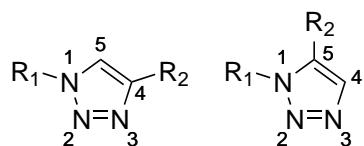
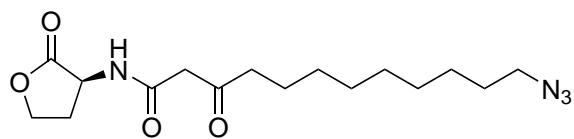


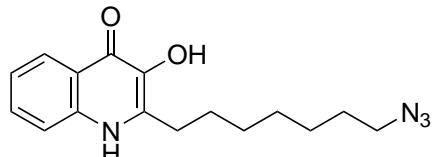
Figure 18: 1,4 (left) and 1,5 (right) triazoles.

7.4.2 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 **73** was synthesised by Ryan Howard, a master's student under my supervision¹⁷⁶ and the tail azide derivative of PQS **74** was synthesised by Ysobel Baker¹⁶¹ (see Figure 19).



73



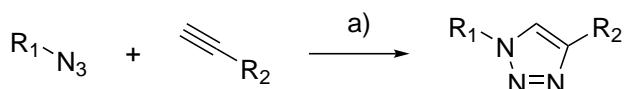
74

Figure 19: Further azido autoinducer derivatives synthesised by Howard¹⁷⁶ 73 and Baker¹⁶¹ 74.

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 9.25.

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.

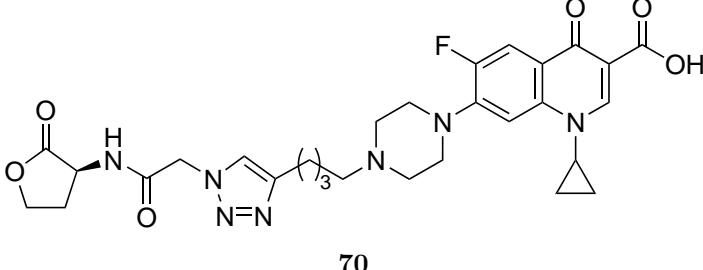
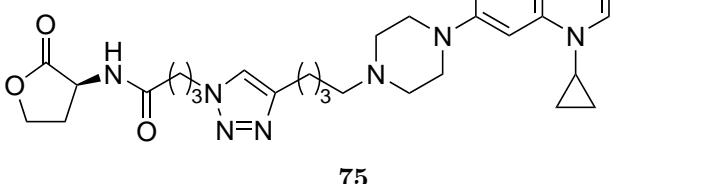
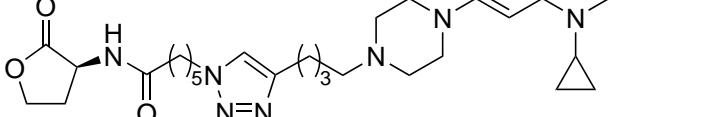
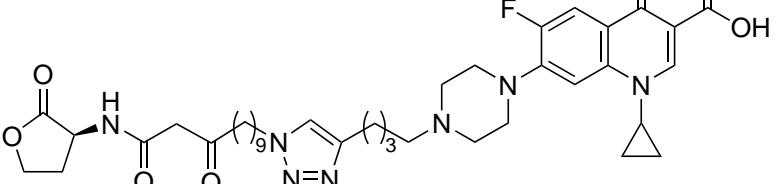
Starting materials	Product	Outcome	Yield
53 and 66	 70	✓ Reaction complete by LCMS in 3 h. Purified by column chromatography (SiO ₂ , 0 - 20 % MeOH/CH ₂ Cl ₂).	29.6 %
56 and 66	 75	✓ Reaction complete by LCMS in 3 h. Purified by column chromatography (SiO ₂ , 0 - 20 % MeOH/CH ₂ Cl ₂).	46.8 %
59 and 66	 76	✓ Reaction complete by LCMS in 3 h. Purified by column chromatography (SiO ₂ , 0 - 20 % MeOH/CH ₂ Cl ₂).	38.0 %
73 and 66	 77	✗ 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
36 and 66		✓ Reaction complete by LCMS in 1.5 h. Purified by prep. HPLC.	27.0 %
47 and 66		✗ Reaction did not go to completion by LCMS. Attempted purification by prep. HPLC but unsuccessful.	
74 and 66		✗ No reaction seen by LCMS.	

Table 6: Click reactions attempted.

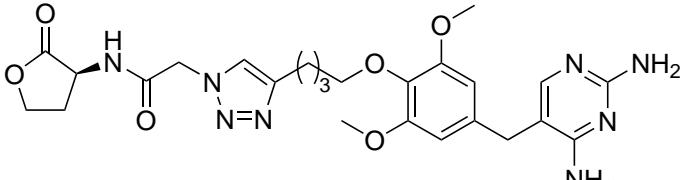
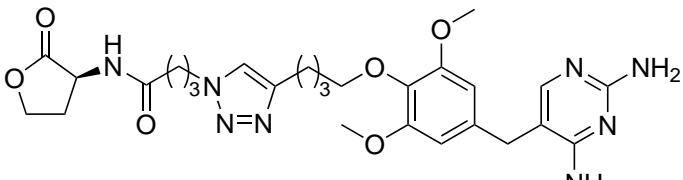
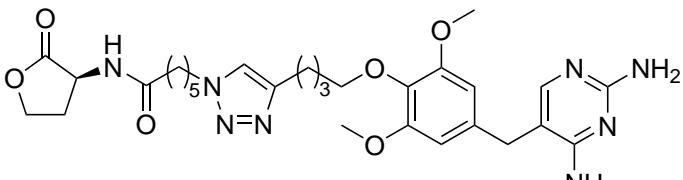
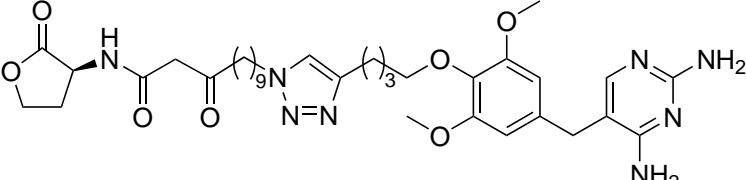
Starting materials	Product	Outcome	Yield
53 and 69		✗ Reaction complete by LCMS in 2 h, but lactone hydrolysed on prep. HPLC column.	
56 and 69		✓ Reaction complete by LCMS in 2 weeks (stalled). Purified by column chromatography (SiO2, 20 % MeOH/CH2Cl2).	16.8 %
59 and 69		✓ Reaction complete by LCMS in 2 weeks (stalled). Purified by column chromatography (SiO2, 20 % MeOH/CH2Cl2).	26.8 %
73 and 69		✗ Degraded during reaction.	

Table 7: Click reactions attempted.

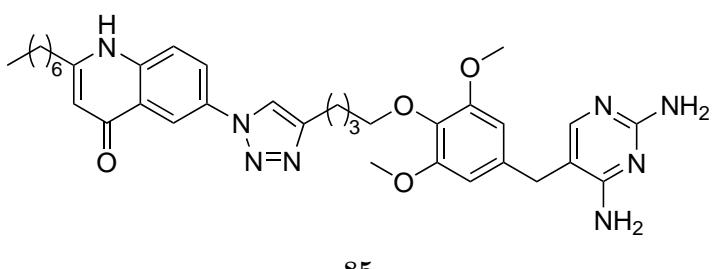
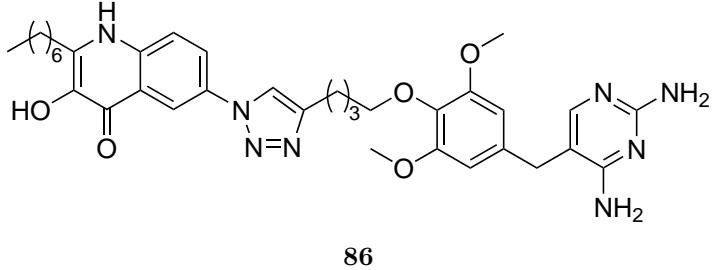
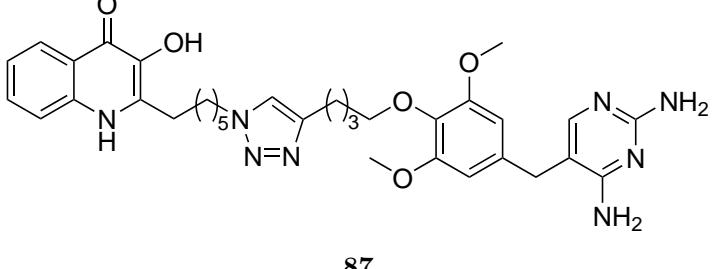
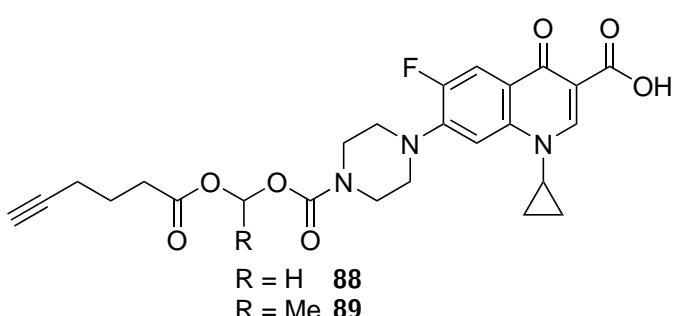
Starting materials	Product	Outcome	Yield
36 and 69		✓ Reaction complete by LCMS in 1.5 h. Purified by prep. HPLC.	41.0 %
47 and 69		✗ Reaction did not go to completion by LCMS. Attempted purification by prep. HPLC but unsuccessful.	
74 and 69		✓ Reaction complete by LCMS in 3 h. Purified by column chromatography (SiO2, 20 % MeOH/CH2Cl2).	18.3 %

Table 8: Click reactions attempted.

7.4.3 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 **88** and **89** (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 **53**, **56** and **59** shown in 7.2.3 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

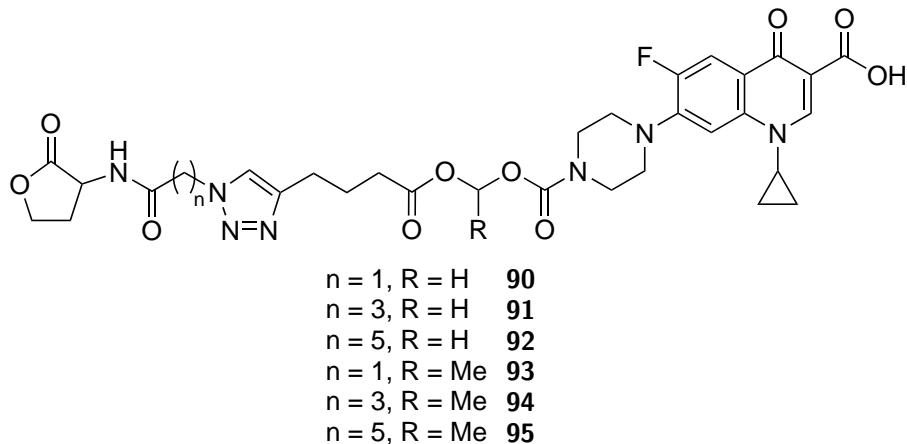


Figure 21: The cleavable HSL-Cip triazole conjugates synthesised by Prof. Sotelo.

In addition, two control compounds **96** and **97** 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.

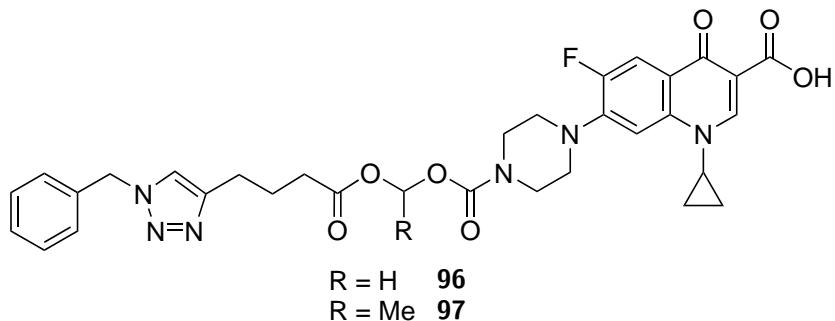


Figure 22: The cleavable Bn-Cip triazole conjugates **96** and **97** synthesised by Prof. Sotelo.

cleavables
intro

8 Results and discussion: HSL analogue-ciprofloxacin conjugates

8.1 Overview

The second part of this project was focused on producing a library of HSL analogue-ciprofloxacin conjugates. The HSL head group was replaced with a selection of cyclic amines found in known quorum sensing modulators (see 5.3.7). The analogues were linked to ciprofloxacin **24** in two ways: directly using either an S_N2 reaction or peptide coupling, and via the triazole linkage shown previously (see 7.4).

8.1.1 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.

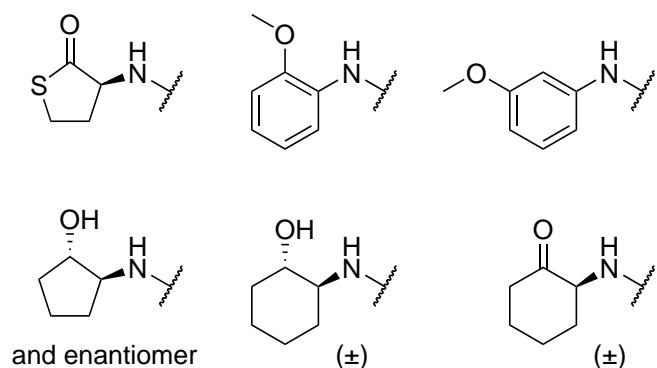
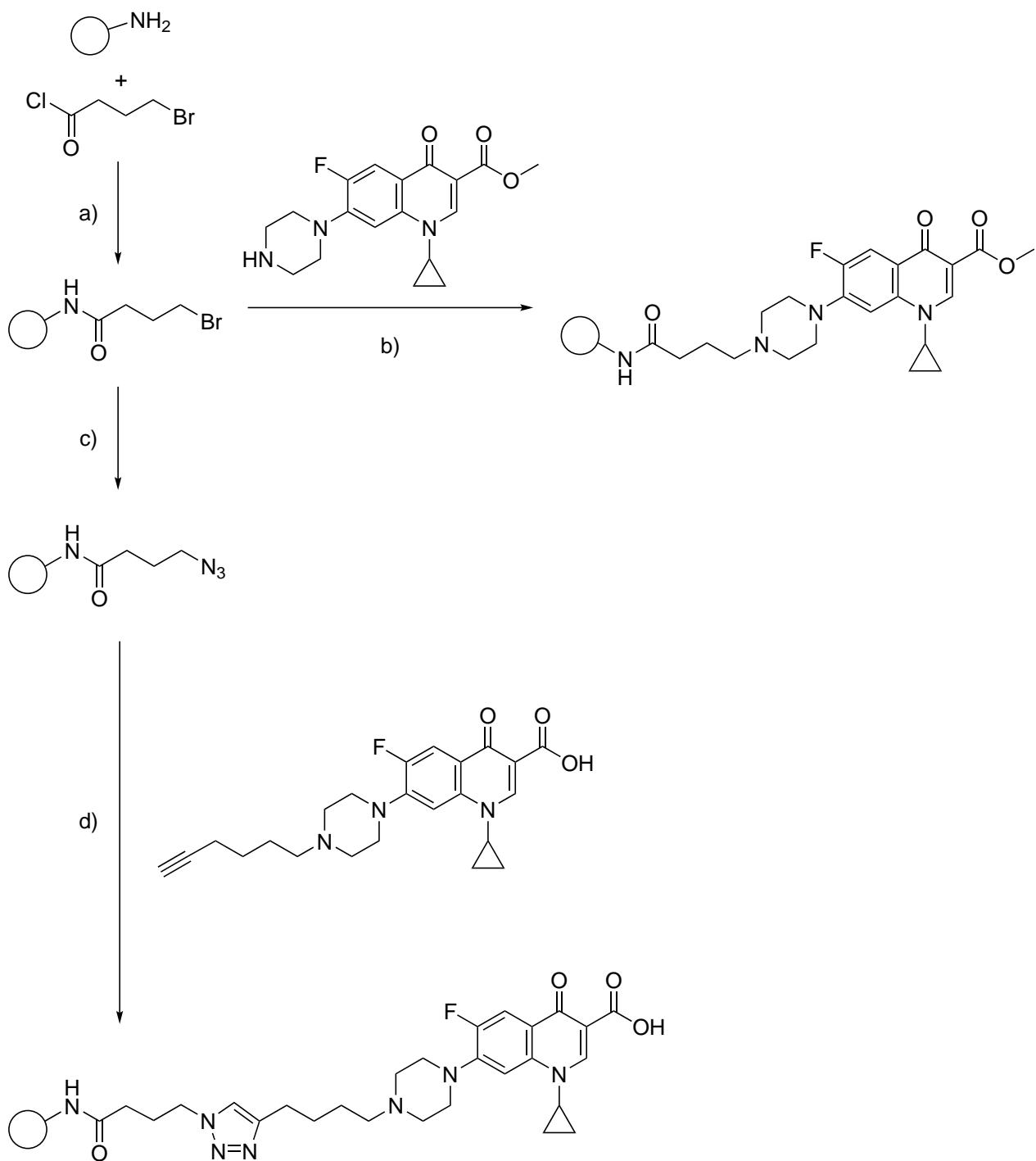


Figure 23: The head groups used in this section.

8.1.2 Library construction

As Ganguly *et al.*¹⁴⁵ (see 5.3.7) 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 **66** made previously to form the triazole-linked product.



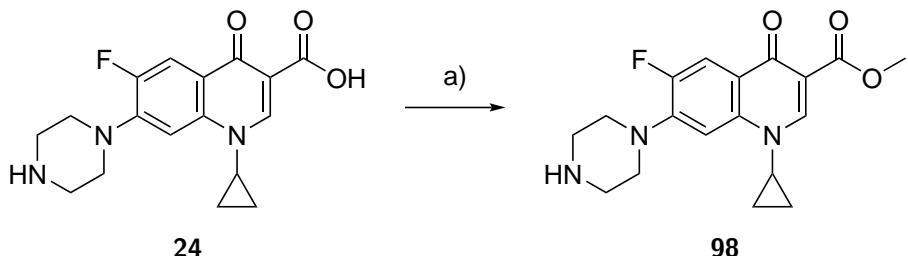
Scheme 11

This strategy was successful for most head groups, but multiple side reactions were observed for the amino alcohol head groups and so other routes to these conjugates were investigated (see 8.5).

8.2 Homocysteine thiolactone derivatives

8.2.1 Synthesis of methyl ciprofloxacin **98**

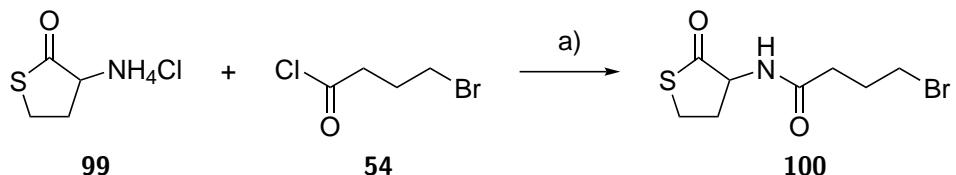
The synthesis of the analogue conjugates began with the synthesis of methyl ciprofloxacin **98** (CipMe), which would then be attached to the various head groups. Methyl ciprofloxacin **98** was synthesised from ciprofloxacin **24** and MeOH in good yield using *para*-toluenesulfonic acid (TsOH) as a catalyst.¹⁷⁷



Scheme 12: Synthesis of methyl ciprofloxacin **98**. a) TsOH, MeOH, 72 h, reflux, 83.3 %.

8.2.2 Synthesis of Br-C₄-HCTL **100**

The HCTL head group was then attached to the linker to form Br-C₄-HCTL **100**, in preparation for coupling to methyl ciprofloxacin **98**. Br-C₄-HCTL **100** was synthesised using the Schotten-Baumann conditions employed previously for the HSL derivatives **55** and **58**. Br-C₄-HCTL **100** was isolated in markedly higher yield than that achieved by Ganguly *et al.*¹⁴⁵ (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.

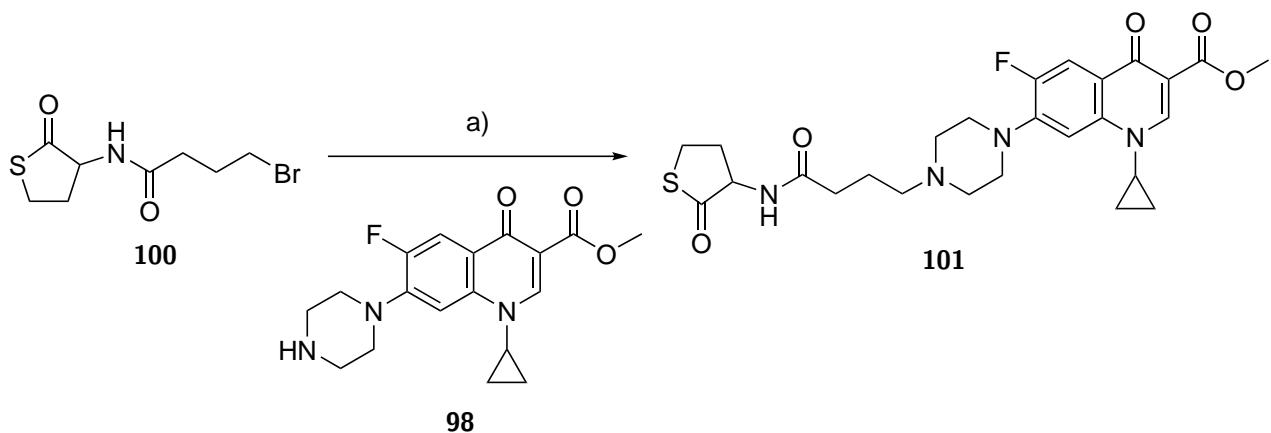


Scheme 13: Synthesis of Br-C₄-HCTL **100**. a) NaHCO₃, CH₂Cl₂, H₂O, 0 °C, 1 h, 87.9 %.

8.2.3 Synthesis of the HCTL-CipMe conjugate **101**

The HCTL-CipMe conjugate **101** was synthesised using the procedure outlined by Ganguly *et al.*¹⁴⁵ (see Scheme 14). Monitoring by LCMS showed slow conversion to the product. Br-C₄-HCTL **100** was presumably consumed by side reactions as 4 eq. were required to reach full conversion. A likely potential side reaction is internal cyclisation of the bromide with the amide NH, and the mass of this molecule was observed by LCMS in the reaction mixture.

Ganguly *et al.* do not quote a yield for this reaction,^{145, 146} 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 **101** for biological testing.

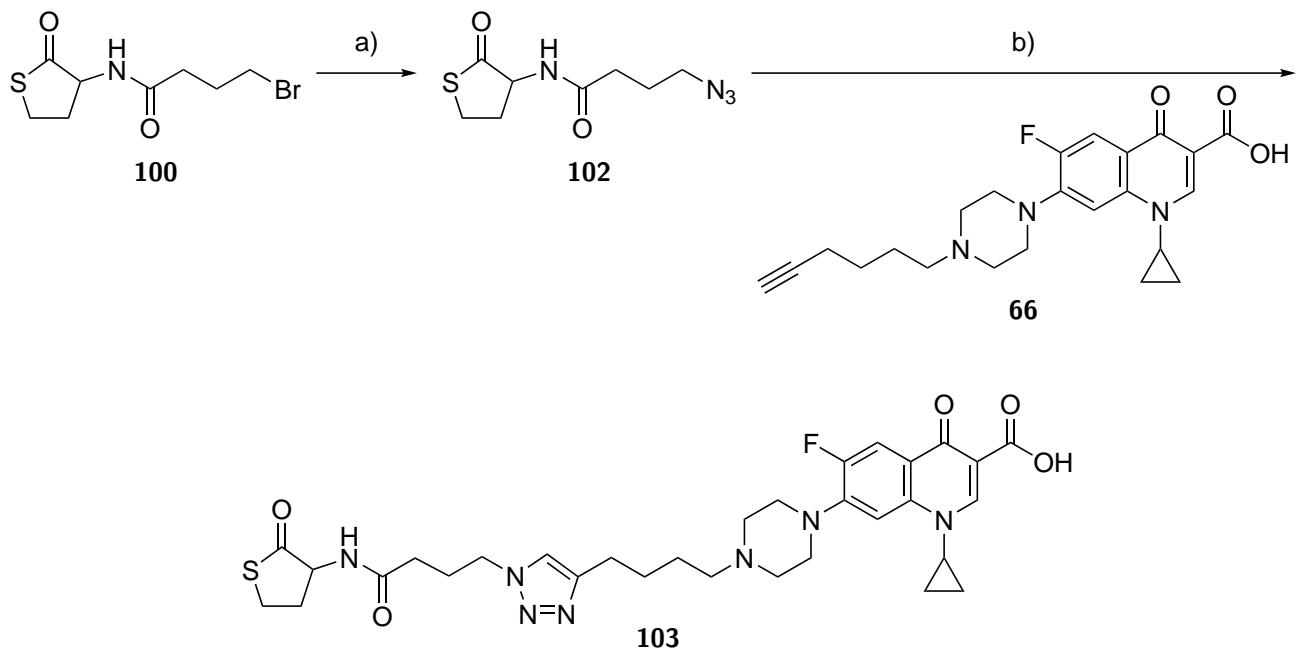


Scheme 14: Synthesis of the HCTL-CipMe conjugate **101**. a) K_2CO_3 , acetonitrile, reflux, 24 h, 12.2 %.

8.2.4 Synthesis of the HCTL-Cip triazole conjugate **103**

$\text{Br-C}_4\text{-HCTL}$ **100** was converted into $\text{N}_3\text{-C}_4\text{-HCTL}$ **102** (see Scheme 14), by an S_N2 reaction with sodium azide which proceeded in excellent yield.

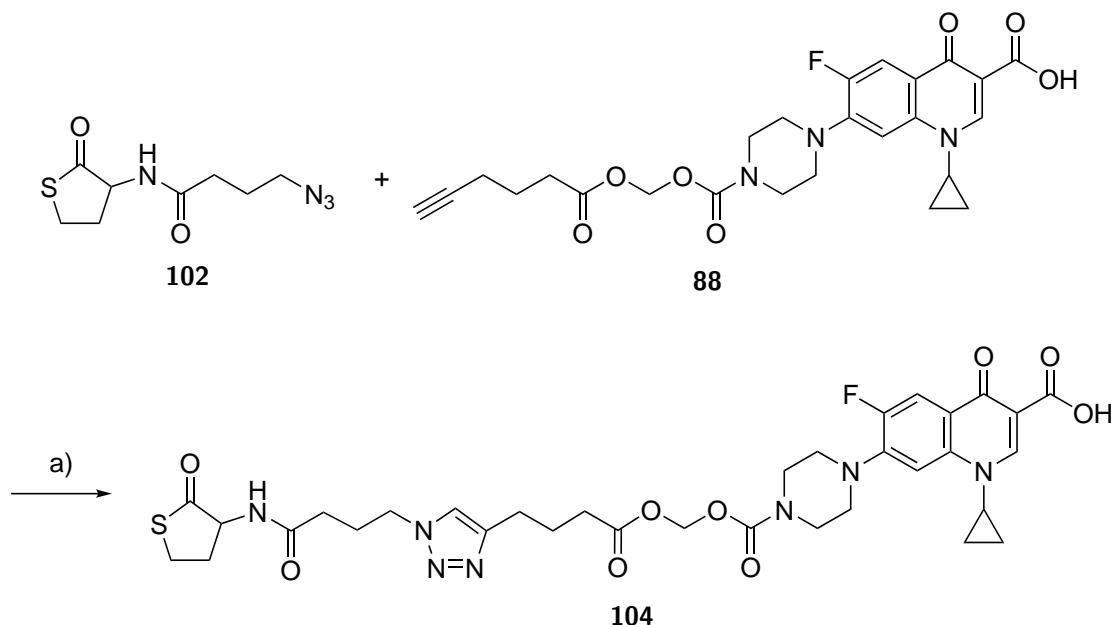
$\text{N}_3\text{-C}_4\text{-HCTL}$ **102** was then subjected to the click reaction conditions optimised previously (see 9.25). The reaction proceeded very slowly at first, as the azide did not dissolve in the reaction solvent and formed a single solid clump. DMSO was added as a co-solvent, and the 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 **103** was isolated in good yield (see Scheme 15).



Scheme 15: Synthesis of the HCTL-Cip triazole conjugate **103**. 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 %.

8.2.5 Synthesis of the cleavable HCTL-Cip triazole conjugate 104

A cleavable conjugate **104** (see Scheme 16) was also synthesised from N₃-C₄-HCTL **102** by reaction with a cleavable alkyne-Cip derivative **88** synthesised previously by Prof. Eddy Sotelo-Perez (see 7.4.3).



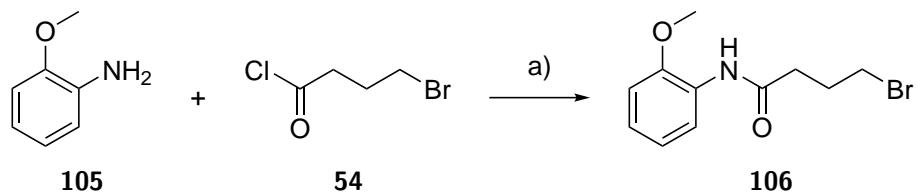
Scheme 16: Synthesis of the cleavable HCTL-Cip triazole conjugate **104**. a) CuI, DIPEA, CH_2Cl_2 , r.t., 3 h, 5.0 %.

8.3 2-Methoxybenzene derivatives

8.3.1 Synthesis of Br-C₄-2-methoxybenzene 106

Br-C₄-2-methoxybenzene **106** was synthesised from 2-methoxyaniline **105** and 4-bromobutyryl chloride **54** using Schotten-Baumann conditions in 50.0 % yield (see Scheme 17). Br-C₄-2-methoxybenzene **106**, like all other 2- and 3-methoxyaniline derivatives mentioned below, appears to be air and/or light sensitive, turning from an initially colourless liquid to blue then black if left out on the bench. It is possible that this sensitivity is due to oxidative polymerisation of the aniline.¹⁷⁸

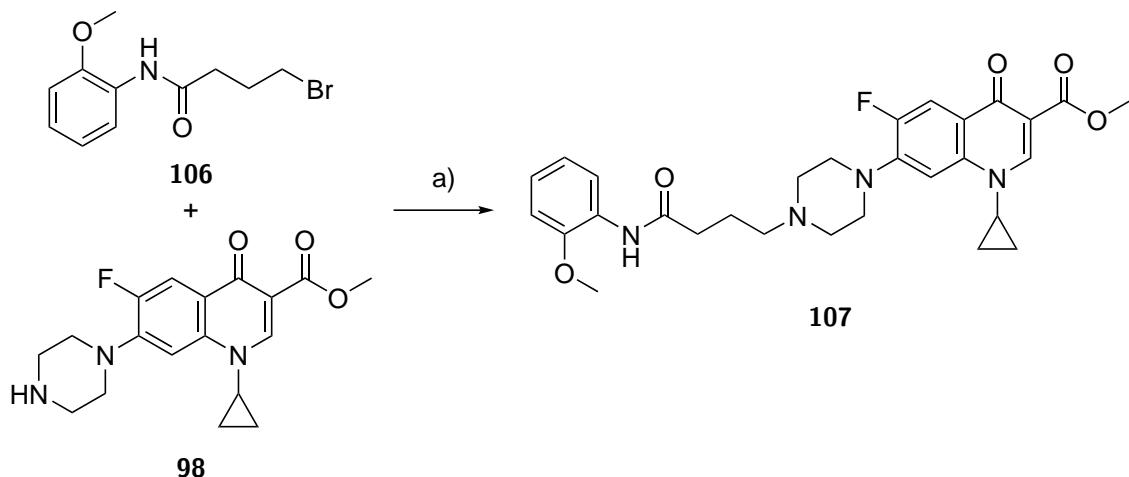
It is likely that the mediocre yield of Br-C₄-2-methoxybenzene **106** is due to degradation during columning, and it is therefore suggested that in future the compound should be used in its crude form to minimise exposure to air and light, as it was fairly pure by ¹H NMR before columning.



Scheme 17: Synthesis of Br-C₄-2-methoxybenzene **106**. a) NaHCO₃, CH₂Cl₂, H₂O, 0 °C, 1 h, 50.0 %.

8.3.2 Synthesis of the 2-methoxybenzene-CipMe conjugate 107

The procedure outlined by Ganguly *et al.*¹⁴⁵ was initially attempted in order to synthesise the 2-methoxybenzene-CipMe conjugate **107**, but the reaction was very slow and did not go to completion, presumably due to degradation of Br-C₄-2-methoxybenzene **106**. New conditions, employing a microwave reactor and 2 eq. of Br-C₄-2-methoxybenzene **106** were then attempted, with a much greater conversion observed by LCMS after 4 h (see Scheme 18). However, a poor yield was obtained, again potentially due to degradation during column chromatography.



Scheme 18: Synthesis of the 2-methoxybenzene-CipMe conjugate **107**. a) NaI, DIPEA, acetonitrile, microwave reactor, 100 °C, 4 h, 10.2 %.

8.3.3 Synthesis of the 2-methoxybenzene-Cip triazole conjugate 109

N₃-C₄-2-methoxybenzene **108** was synthesised from Br-C₄-2-methoxybenzene **106** by an S_N2 reaction with sodium azide (see ??). The yield of N₃-C₄-2-methoxybenzene **108** (26.7 %) was a lot lower than for N₃-C₄-HCTL **102** (89.3 %). The colour of N₃-C₄-2-methoxybenzene **108**, like its precursor, changed from clear to blue then black, suggesting that it is also air/light sensitive. However, in this case it may not be better to use this product crude as several additional impurities, apparently caused by S_N2 reactions at the bromide, could be observed by LCMS (see Figure 24).

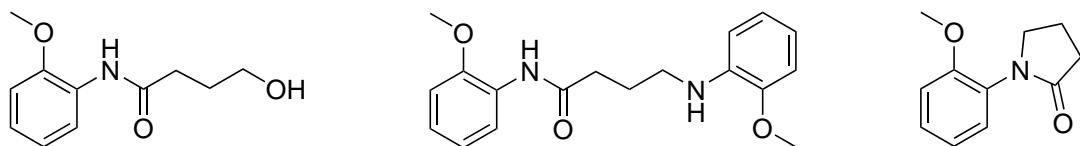
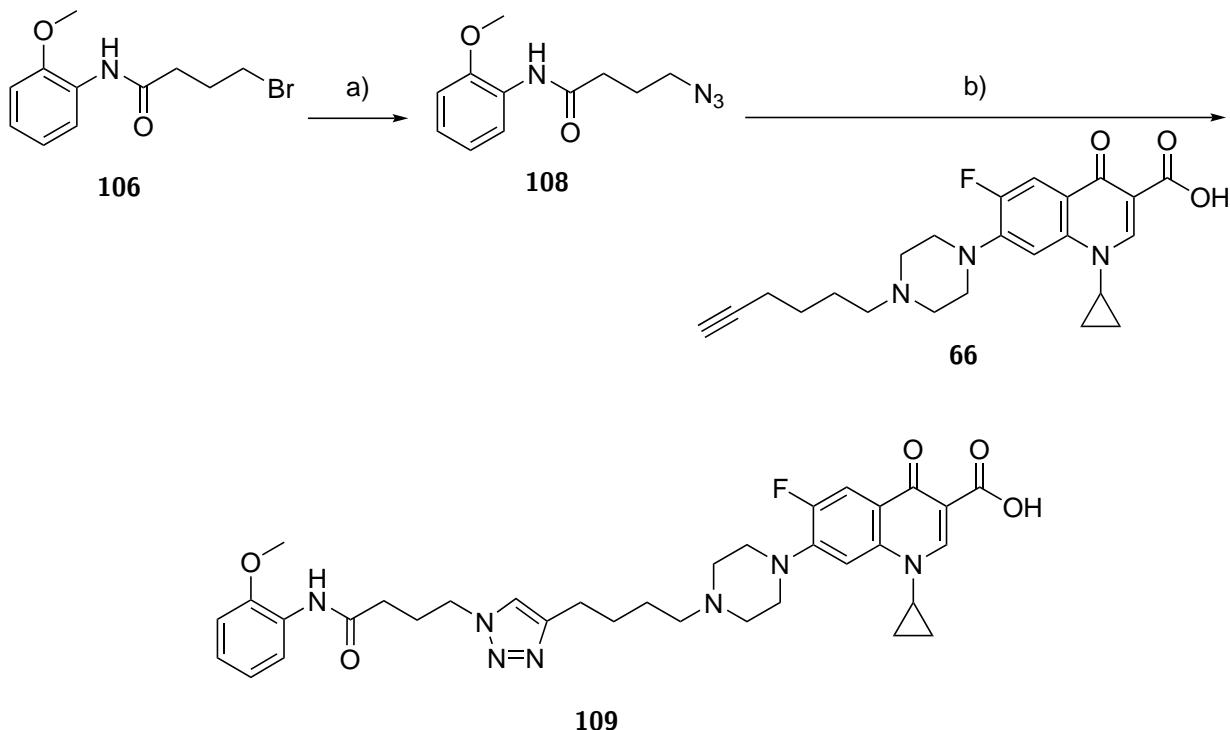


Figure 24: Suspected impurities observed by LCMS during the synthesis of N₃-C₄-2-methoxybenzene **108**.

The 2-methoxybenzene-Cip triazole conjugate **109** was synthesised using the standard click conditions (see 9.25), with the addition of CH₂Cl₂ as a co-solvent to aid the dissolution of N₃-C₄-2-methoxybenzene **108** (see Scheme 19). Again, the yield was low, probably due to air/light sensitivity of the starting material and/or product.

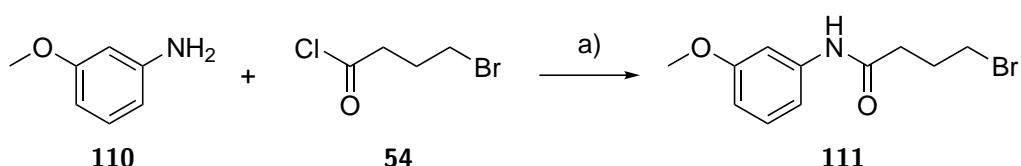


Scheme 19: Synthesis of the 2-methoxybenzene-Cip triazole conjugate **109**. a) NaN_3 , acetonitrile, reflux, 2 h, 26.7 %. b) CuSO_4 , THPTA, sodium ascorbate, H_2O , *t*-BuOH, CH_2Cl_2 , r.t., 16 h, 39.0 %.

8.4 3-Methoxybenzene derivatives

8.4.1 Synthesis of Br-C₆-3-methoxybenzene 111

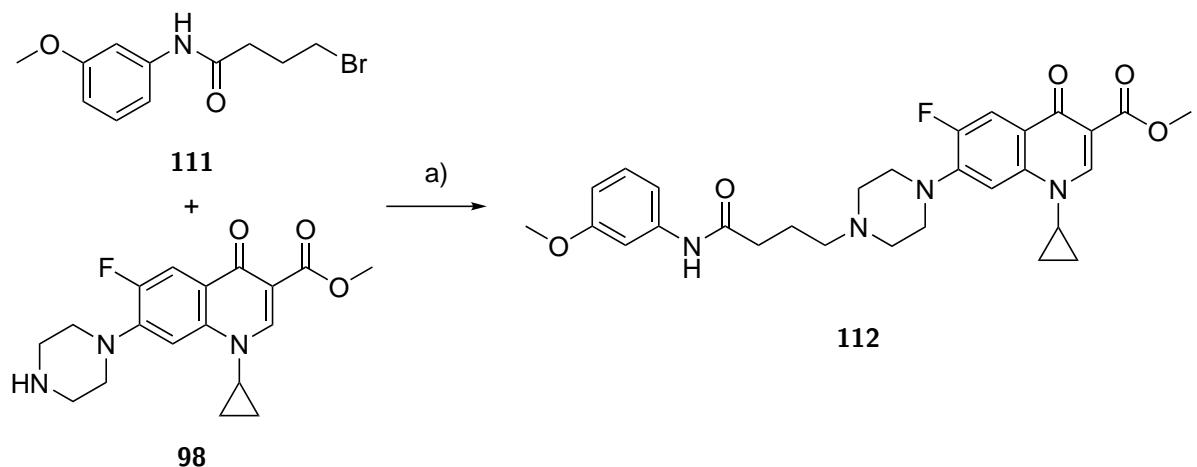
Br-C₄-3-methoxybenzene **111** was synthesised from 3-methoxyaniline **110** and 4-bromobutyryl chloride **54** using Schotten-Baumann conditions as above in almost identical (49.6 %) yield (see Scheme 20). The compound is probably also air and/or light sensitive, turning from a pale pink amorphous solid to a pale brown liquid.



Scheme 20: Synthesis of Br-C₄-3-methoxybenzene **106**. a) NaHCO₃, CH₂Cl₂, H₂O, 0 °C, 1 h, 49.6 %.

8.4.2 Synthesis of the 3-methoxybenzene-CipMe conjugate 112

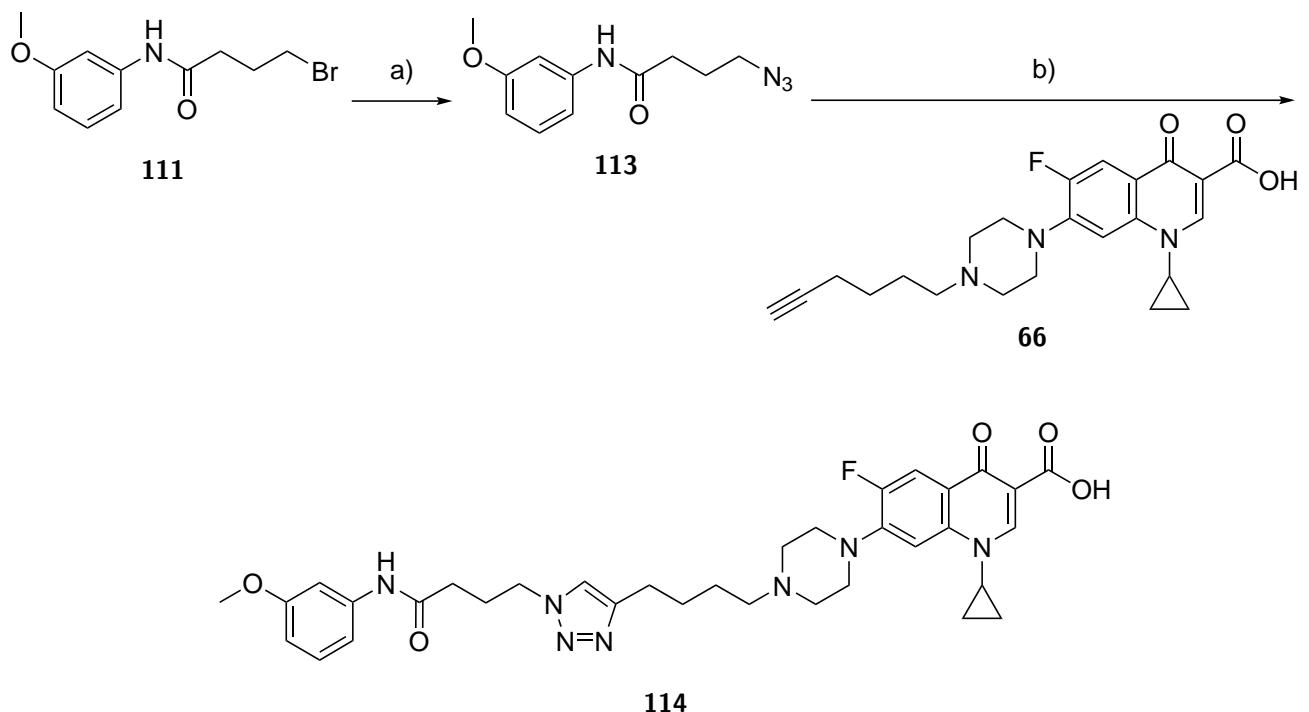
The 3-methoxybenzene-CipMe conjugate **112**, was synthesised as above, in similar yield (see Scheme 21).



Scheme 21: Synthesis of the 3-methoxybenzene-CipMe conjugate **112**. a) NaI , DIPEA, acetonitrile, microwave reactor, $100\text{ }^\circ\text{C}$, 4 h, 10.5 %.

8.4.3 Synthesis of the 3-methoxybenzene-Cip triazole conjugate **114**

$\text{N}_3\text{-C}_4\text{-2-methoxybenzene}$ **108** and the 3-methoxybenzene-Cip triazole conjugate **114** were synthesised as above, in similar yields (see Scheme 21 and Scheme 22).

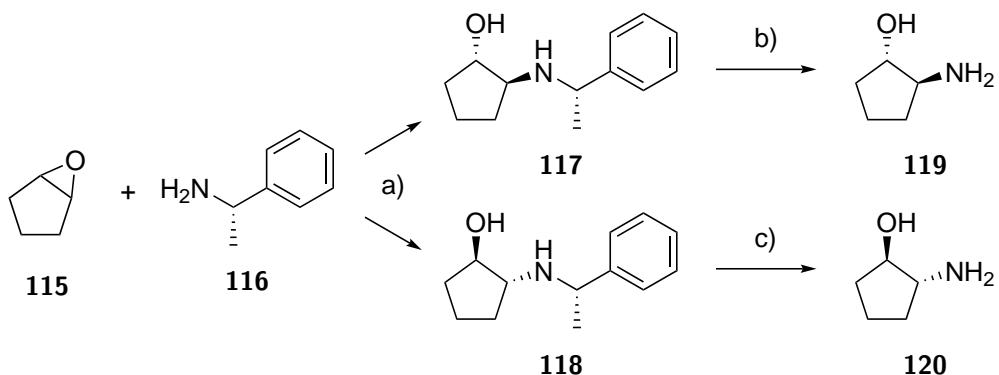


Scheme 22: Synthesis of the 3-methoxybenzene-Cip triazole conjugate **114**. a) NaN_3 , acetonitrile, reflux, 7 h, 16.7 %. b) CuSO_4 , THPTA, sodium ascorbate, H_2O , $t\text{-BuOH}$, CH_2Cl_2 , r.t., 2 h, 5.0 %.

8.5 Cyclopentanol derivatives

8.5.1 Synthesis of the 2-aminocyclopentan-1-ol head groups **119** and **120**

Synthesis of the cyclopentanol derivatives began with the synthesis of $(1S,2S)$ -2-aminocyclopentan-1-ol **119** and $(1R,2R)$ -2-aminocyclopentan-1-ol **120** (see Scheme 23), using a procedure reported by Overman and Sugai.^{179–181} These precursors were synthesised by opening cyclopentene oxide **115** using (S) -1-phenylethanimine **116** to give approximately equal amounts of two diastereomers, **117** and **118**, which were separated using column chromatography. The removal of the methylbenzyl groups proved more difficult than expected, with the conditions reported by Overman and Sugai¹⁸⁰ 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, **119** and **120**, both in quantitative yield.



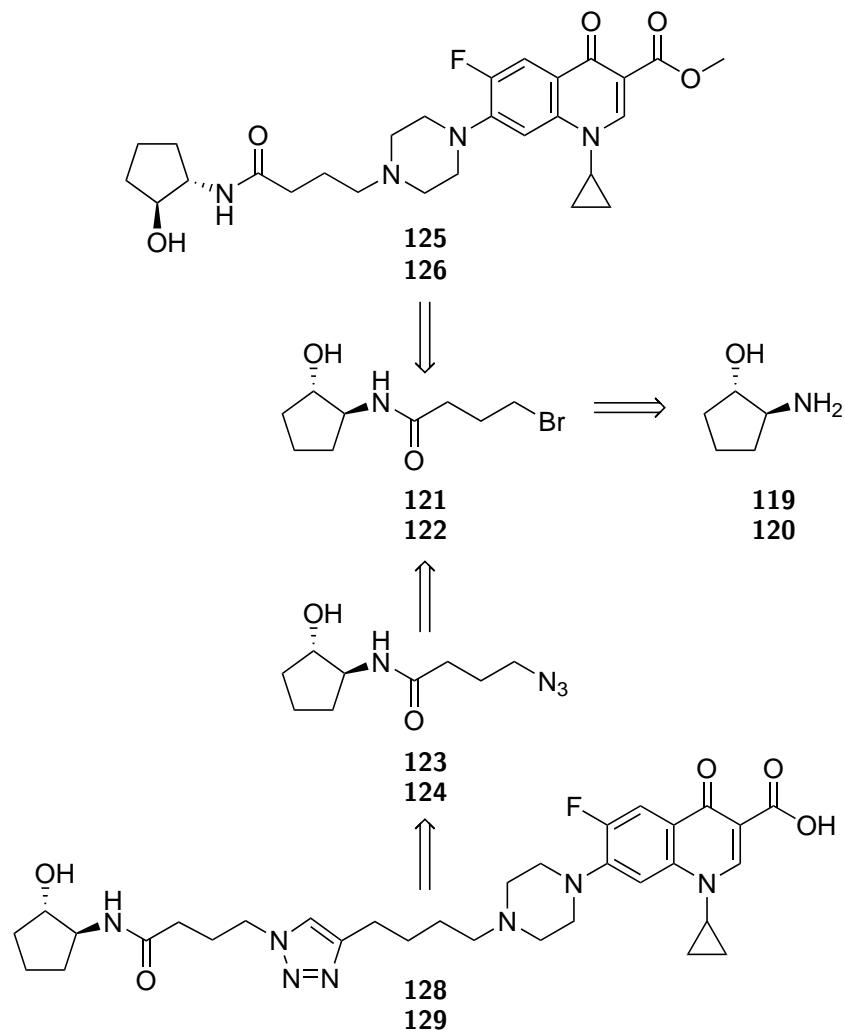
Scheme 23: Synthesis of $(1S,2S)$ -2-aminocyclopentan-1-ol **119** and $(1R,2R)$ -2-aminocyclopentan-1-ol **120**. a) $AlMe_3$, CH_2Cl_2 , $0\text{ }^\circ C$, **117** (*SSS*): 35.2 %, **118** (*RRS*): 32.1 %. b) See Table 9. c) $Pd(OH)_2$, $MeOH$, H_2 , 5 atm, r.t., 1 d, 100 %.

Conditions	Temperature and pressure	Time	Result
117 · HCl, ammonium formate, 10 % Pd/C, DMF	r.t., 1 atm	2 d	117 salt
117 , ammonium formate, 10 % Pd/C, DMF	r.t., 1 atm	2 d	117 salt
117 · HCl, ammonium formate, 10 % Pd/C, dry DMF	r.t., 1 atm	2 d	117 salt
118 , ammonium formate, 10 % Pd/C, dry DMF	r.t., 1 atm	2 d	118 salt
117 , ammonium formate, 10 % Pd/C, dry DMF	70 °C, 1 atm	1 d	117 salt
117 , ammonium formate, 10 % Pd/C, dry DMF, AcOH	70 °C, 1 atm	1 d	Complex mixture
117 · HCl, dry ammonium formate, 10 % Pd/C, dry DMF	120 °C, 1 atm	7 d	Complex mixture
117 · HCl, Pd(OH) ₂ , MeOH, H ₂	r.t., 1 atm	1 d	117 salt
117 · HCl, Pd(OH) ₂ , MeOH, H ₂	r.t., 3.4 atm	1 d	119 salt, 117 salt, and an unidentified compound (approx. 7:2:10 by ¹ H NMR)
117 , Pd(OH) ₂ , MeOH, H ₂	r.t., 5 atm	1 d	119 , 100 % yield

Table 9: Conditions attempted for the synthesis of (*1S,2S*)-2-aminocyclopentan-1-ol **119** and (*1R,2R*)-2-aminocyclopentan-1-ol **120** (see Scheme 23).

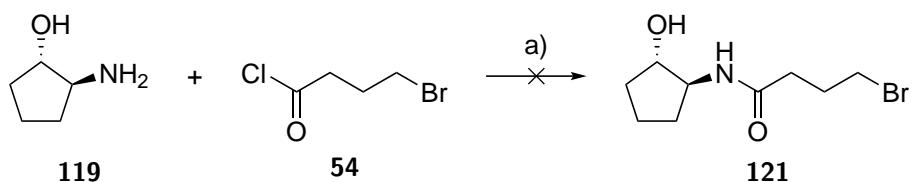
8.5.2 Initial branching route

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 **125** (*SS*) and **126** (*RR*), and the cyclopentanol-Cip triazole conjugates **128** (*SS*) and **129** (*RR*). *SS* enantiomers are shown, but both are implied.

Synthesis of Br-C₄-cyclopentanol-(*SS*) **121** from (1*S*,2*S*)-2-aminocyclopentan-1-ol **119** and 4-bromobutyryl chloride **54** 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 8.5.3), using 4-chlorobutyryl chloride **143** as the linker instead of 4-bromobutyryl chloride **54** (see 8.5.4), and installing the linker on methyl ciprofloxacin **98** and then attaching the head group by peptide coupling (see 8.5.5).



Scheme 25: Attempted synthesis of Br-C₄-cyclopentanol-(*SS*) **121**. a) NaHCO₃, CH₂Cl₂, H₂O, 0 °C, 2 h.

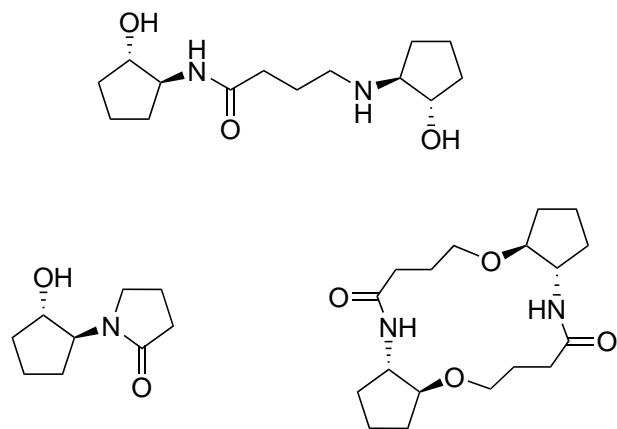
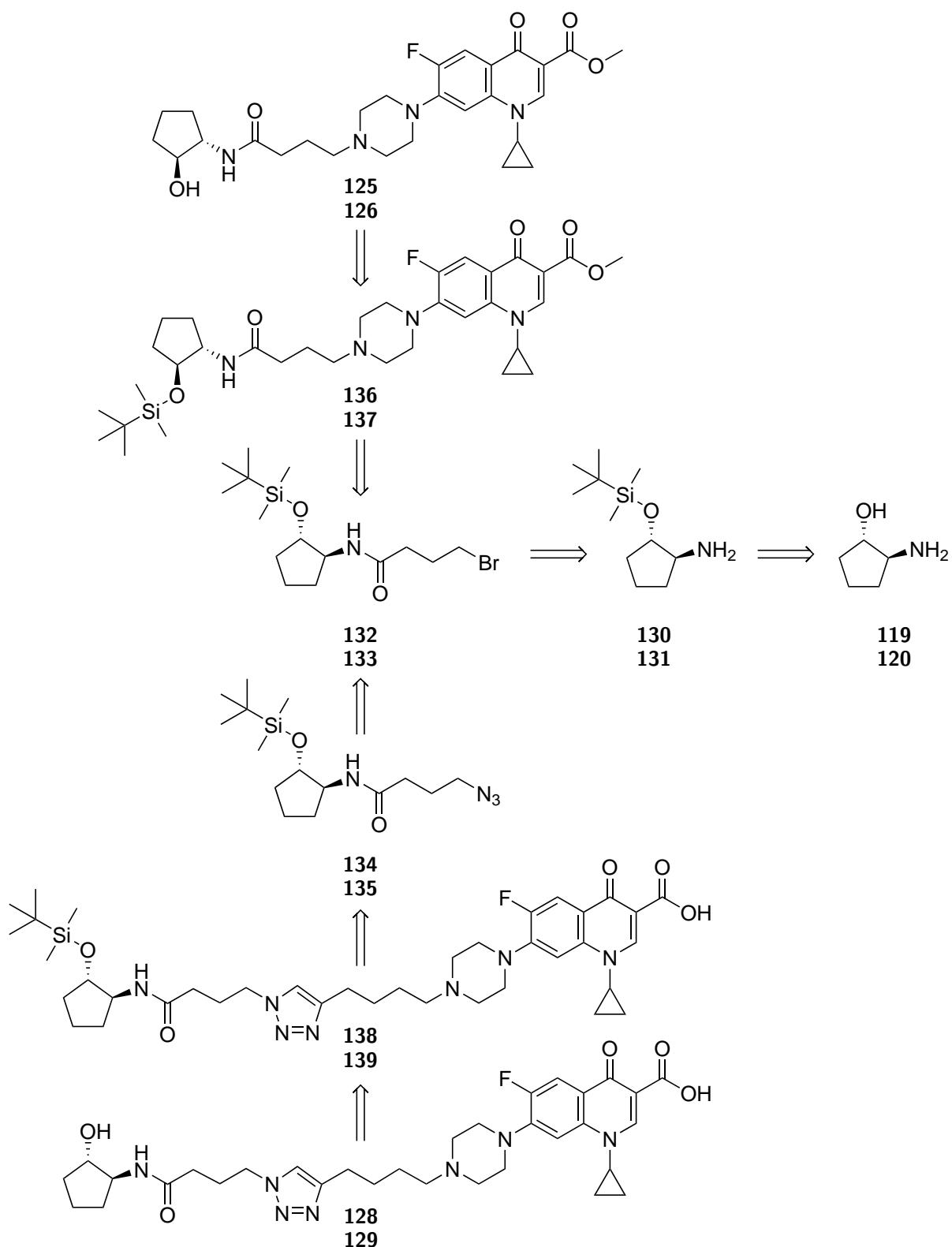


Figure 25: Suspected impurities observed by LCMS during the synthesis of Br-C₄-cyclopentanol-(SS) **121**. Regiochemistry is speculative.

8.5.3 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) **121** and N₃-C₄-cyclopentanol-(SS) **123** could be purified. The TBDMS group could be removed later in the synthesis using TBAF or acid.

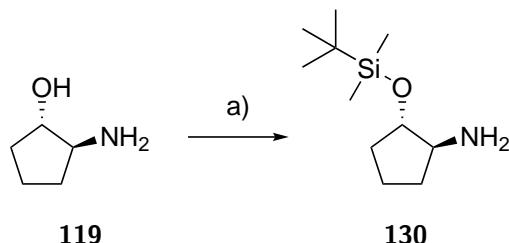


Scheme 26: Retrosynthetic of the cyclopentanol-CipMe conjugates **125** (*SS*) and **126** (*RR*), and the cyclopentanol-Cip triazole conjugates **128** (*SS*) and **129** (*RR*) using a TBDMS protection strategy. *SS* enantiomers are shown, but both are implied.

8.5.3.1 Synthesis of TBDMS-protected (1*S*,2*S*)-2-aminocyclopentan-1-ol **119**

The synthesis began with the optimisation of the protection of (1*S*,2*S*)-2-aminocyclopentan-1-ol **119** 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. al¹⁸² 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.



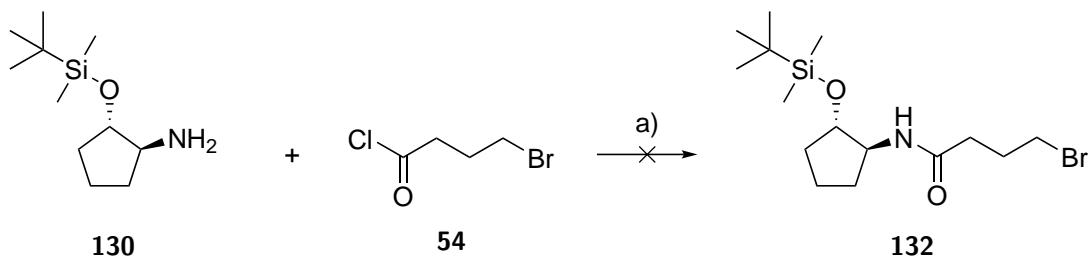
Scheme 27: Synthesis of TBDMS protected (*1S,2S*)-2-aminocyclopentan-1-ol **130**. a) See Table 10.

Conditions	Temperature	Time	Result
TBDMSCl, DMAP, TEA, CH_2Cl_2 ¹⁸³	r.t.	18 h	Trace of 130 , mostly 119
TBDMSCl, imidazole, CH_2Cl_2 ¹⁸⁴	0 °C	1 h	119
TBDMSCl, DBU, acetonitrile ¹⁸⁵	0 °C	1 d	119
TBDMSOTf, TEA, CH_2Cl_2 , ¹⁸² aq. workup then column	0 °C	6 h	130 , 97.7 % yield

Table 10: Conditions attempted for the synthesis of $(1S,2S)$ -2-((*tert*-butyldimethylsilyl)oxy)cyclopentan-1-amine **130** (see Scheme 28).

8.5.3.2 Synthesis of Br-C₄-cyclopentanol-TBDMS-(SS) 132

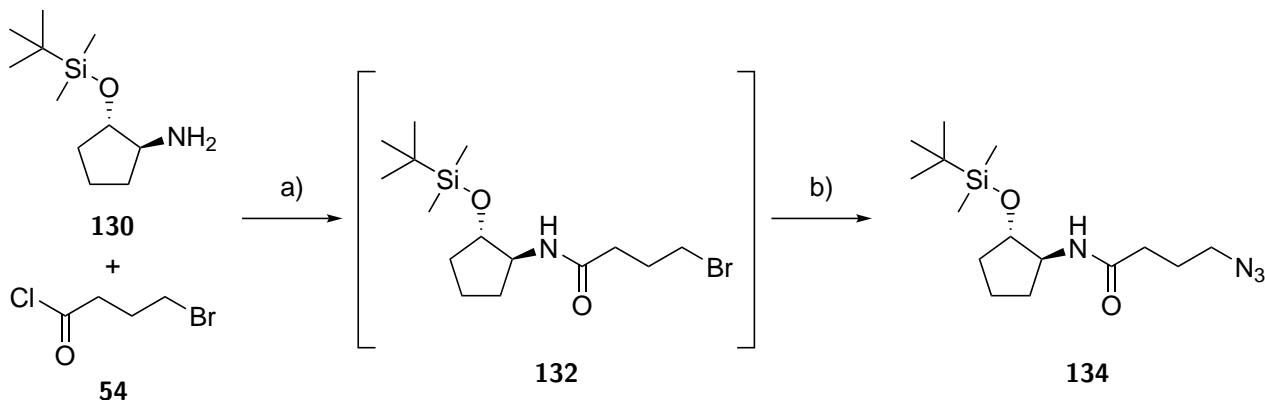
The TBDMS protected (1*S*,2*S*)-2-aminocyclopentan-1-ol **130** was reacted with 4-bromobutyryl chloride **54** to form Br-C₄-cyclopentanol-TBDMS-(*SS*) **132**. The reaction was observed to go to completion by TLC, but it became apparent that the product was reacting further during concentration and purification. Adding sodium azide to the mixture obtained after the failed purification attempts was observed to convert the remaining Br-C₄-cyclopentanol-TBDMS-(*SS*) **132** to N₃-C₄-cyclopentanol-TBDMS-(*SS*) **134**. 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) **132**. a) NaHCO₃, CH₂Cl₂, H₂O, 0 °C, 2 h.

8.5.3.3 Synthesis of $\text{N}_3\text{-C}_4\text{-cyclopentanol-TBDMS-(SS) 134}$ by one-pot reaction

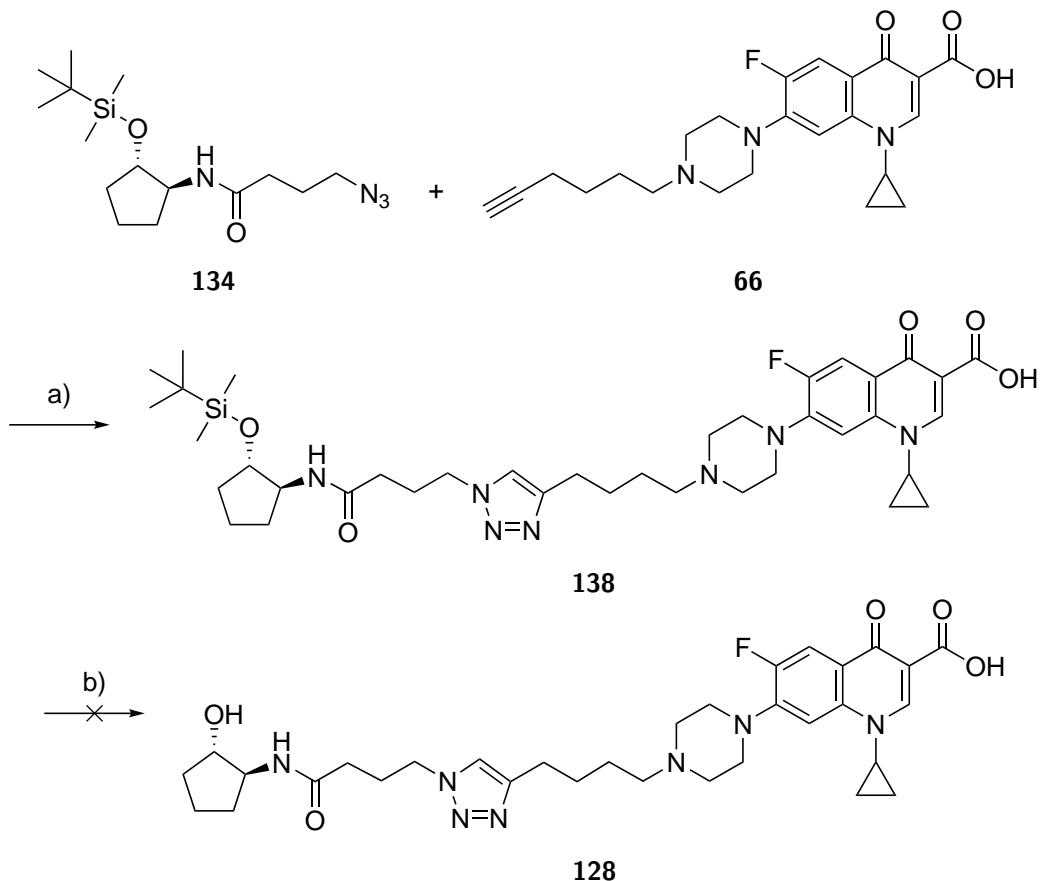
$\text{N}_3\text{-C}_4\text{-cyclopentanol-TBDMS-(SS) 134}$ was finally synthesised by a two-step, one-pot reaction. Schotten-Baumann conditions were used to form the bromide. The water was then removed, and DMF and sodium azide were added. $\text{N}_3\text{-C}_4\text{-cyclopentanol-TBDMS-(SS) 134}$ was produced in excellent yield.



Scheme 29: Synthesis of $\text{N}_3\text{-C}_4\text{-cyclopentanol-TBDMS-(SS) 134}$. 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.

8.5.3.4 Synthesis of the (SS)-TBDMS-cyclopentanol-Cip triazole conjugate 138

$\text{N}_3\text{-C}_4\text{-cyclopentanol-TBDMS-(SS) 134}$ and the alkynyl ciprofloxacin derivative 66 were subjected to standard click conditions (see 9.25), and the (SS)-TBDMS-cyclopentanol-Cip triazole conjugate 138 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 128 by column chromatography was not successful due to streaking and poor separation. Purification using DOWEX resin and CaCO_3^{186} 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.

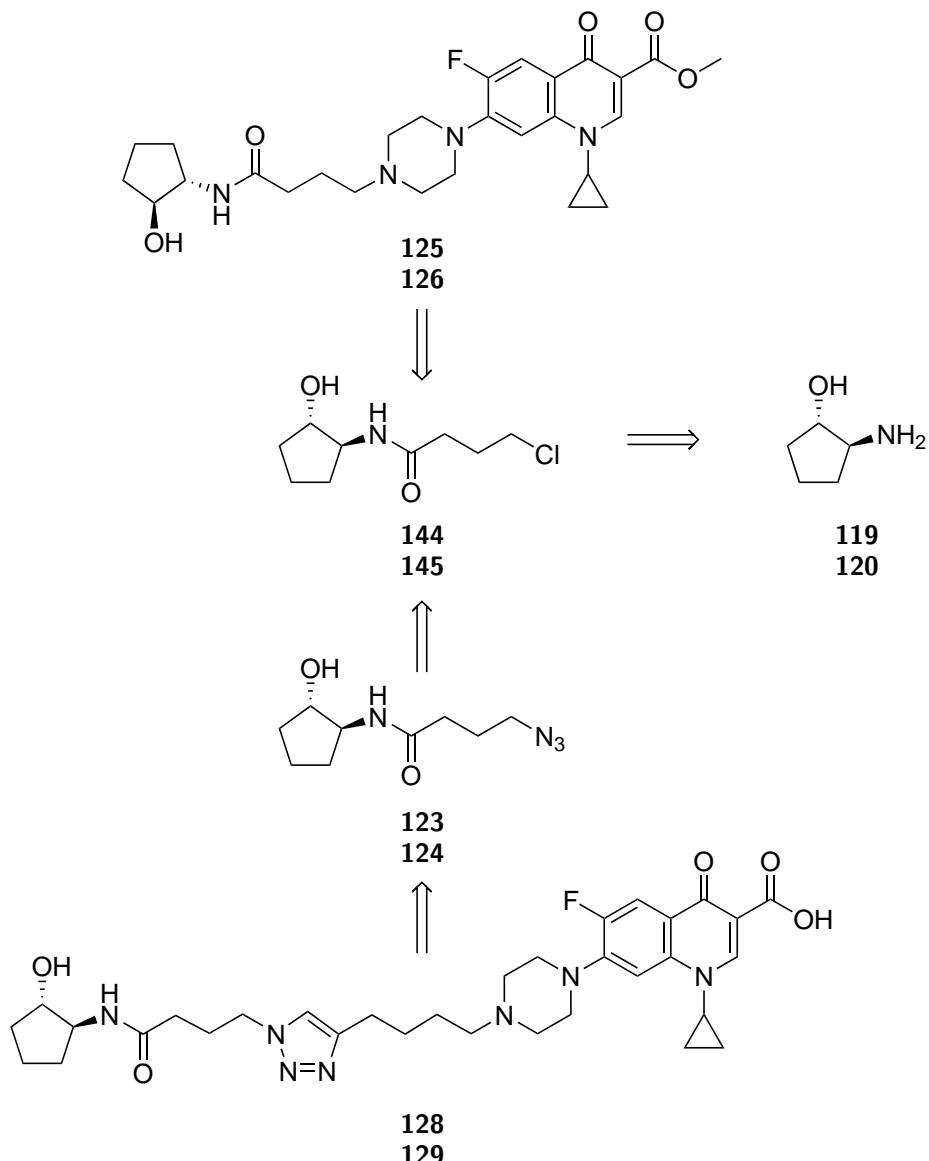


Scheme 30: Synthesis of the (SS)-TBDMS-cyclopentanol-Cip triazole conjugate **138**. a) CuSO_4 , sodium ascorbate, THPTA, H_2O , *t*-BuOH, r.t., 87.4 %. b) TBAF, THF, r.t., 16 h.

8.5.4 Synthesis of the cyclopentanol-Cip triazole conjugates **128** and **129** via chloride intermediates

Given that the side product formation seen in the previous sections was most likely due to $\text{S}_{\text{N}}2$ attack on the bromide, we decided to use a chloride rather than a bromide intermediate (see Scheme 24 and Scheme 31 to compare). The bromide intermediate was initially chosen as it was used by Ganguly et. al.¹⁴⁵ but it was anticipated that using a chloride would reduce the side reactions seen with the more reactive bromide.

sort
num-
bering



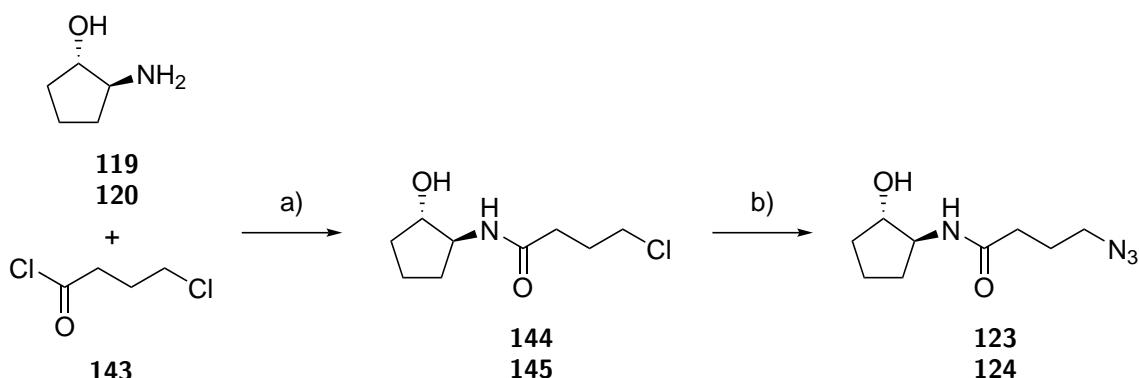
Scheme 31: Retrosynthesis of the cyclopentanol-CipMe conjugates **125** (*SS*) and **126** (*RR*), and the cyclopentanol-Cip triazole conjugates **128** (*SS*) and **129** (*RR*) via Cl-C₄-cyclopentanol intermediates **144** (*SS*) and **145** (*RR*). *SS* enantiomers are shown, but both are implied.

Attempts at this route began with the synthesis of Cl-C₄-cyclopentanol-(*RR*) **145**. 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.*¹⁸⁷ 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 **120** 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*) **145** in good yield (64.1 %). Unlike the bromide **121**, the chloride **145** was stable when concentrated.

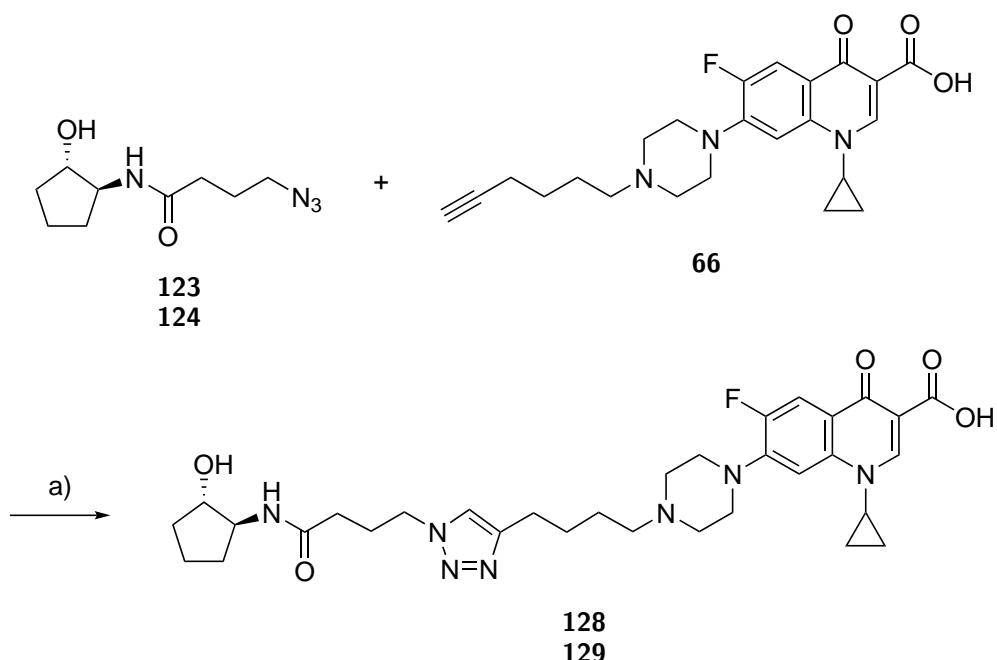
Cl-C₄-cyclopentanol-(*RR*) **145** was converted to N₃-C₄-cyclopentanol-(*RR*) **124** by reaction with sodium azide. The reaction was slower than with previous bromides (~16 h vs. ~2 h), but much cleaner than with Br-C₄-cyclopentanol-(*SS*) **121** (see 8.5.2).

The enantiomers Cl-C₄-cyclopentanol-(*SS*) **144** and N₃-C₄-cyclopentanol-(*SS*) **123** were synthesised in lower yields, in part because of the smaller amounts being used.



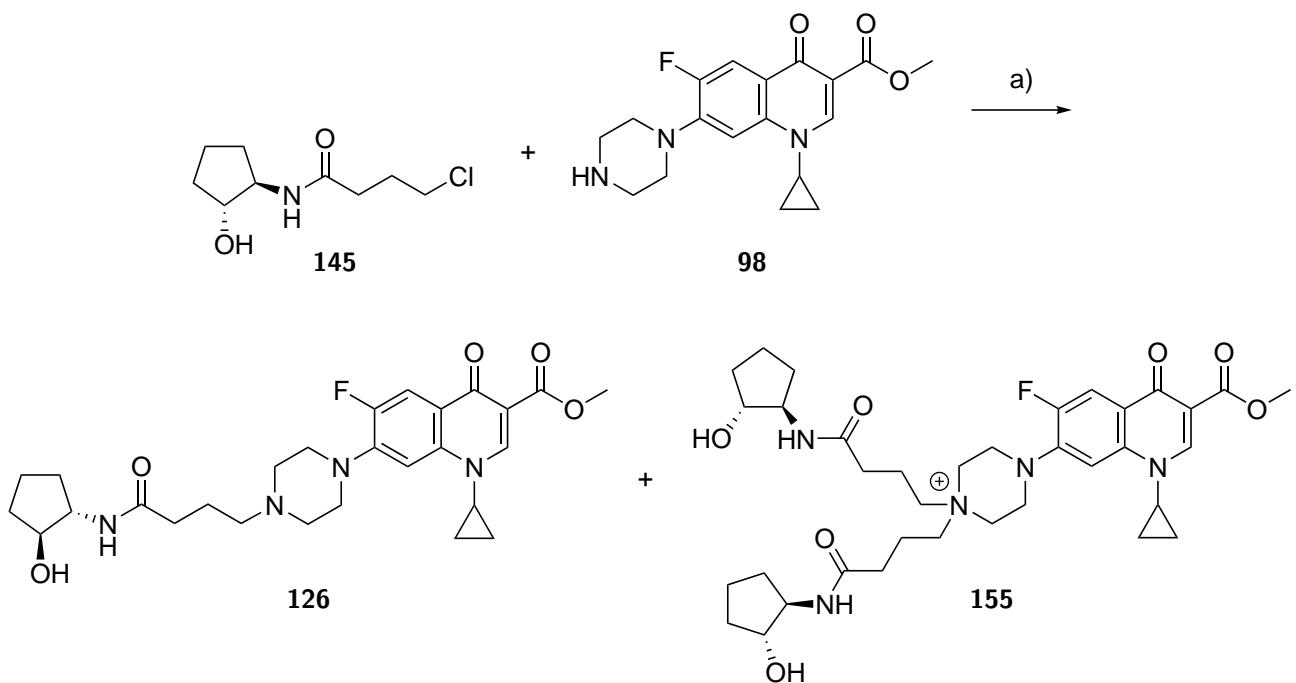
Scheme 32: Synthesis of N₃-C₄-cyclopentanol-(*SS*) **123** and N₃-C₄-cyclopentanol-(*RR*) **124**. *SS* enantiomers are shown, but both were synthesised. a) TEA, CH₂Cl₂, 0 °C, 2 h, **144** (*SS*): 24.2 %, **145** (*RR*): 64.1 %. b) NaN₃, acetonitrile, 50 °C, 16 h, **123** (*SS*): 45.0 %, **124** (*RR*): 87.6 %.

The cyclopentanol-Cip triazole conjugates **128** (*SS*) and **129** (*RR*) were synthesised using standard click conditions (see 9.25). 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 33: Synthesis of the cyclopentanol-Cip triazole conjugates **128** (*SS*) and **129** (*RR*). *SS* enantiomers are shown, but both were synthesised. a) CuSO₄, THPTA, sodium ascorbate, H₂O, *t*-BuOH, r.t., 16 h, **128** (*SS*): 22.2 %, **129** (*RR*): 27.1 %.

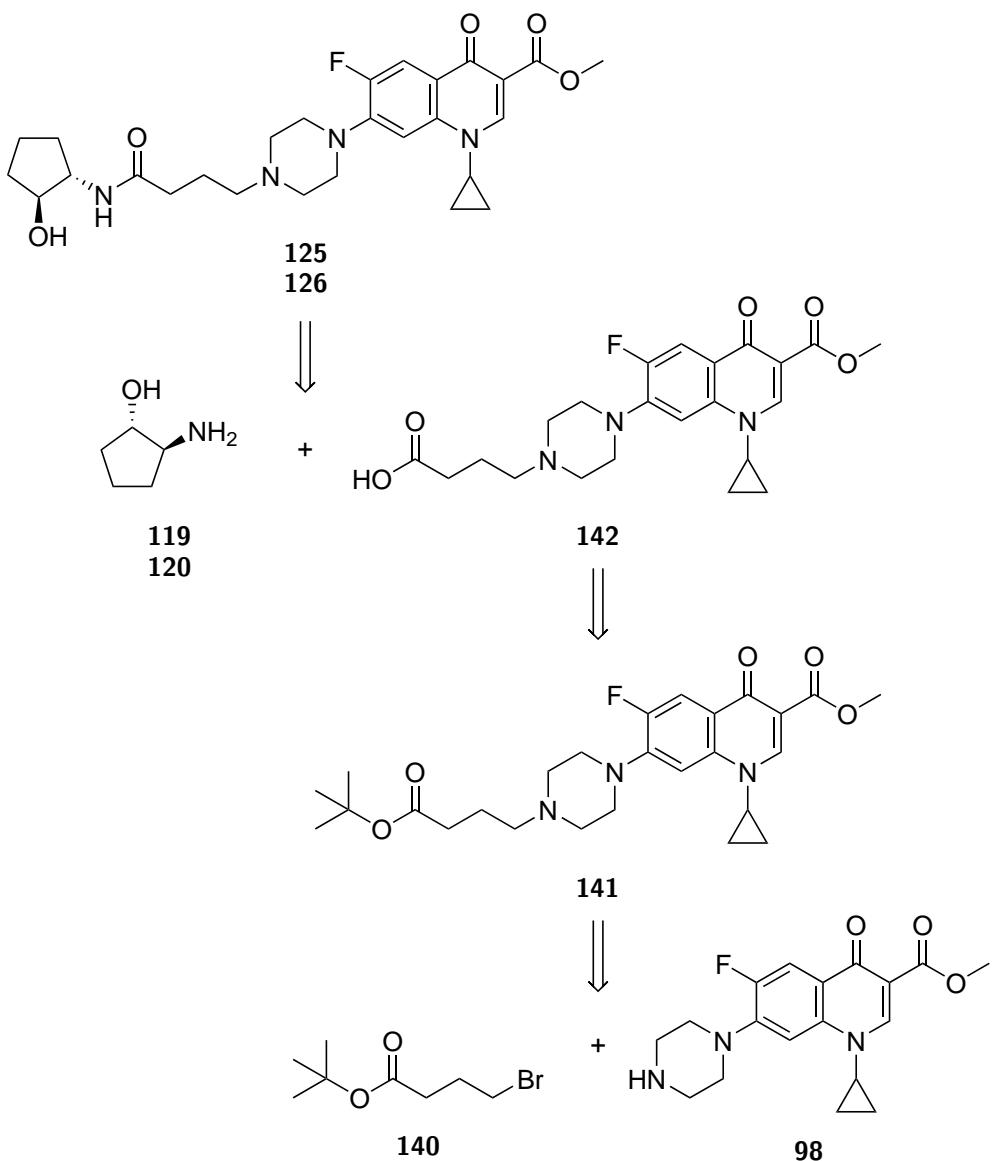
The S_N2 reaction of Cl-C₄-cyclopentanol-(*RR*) **145** and methyl ciprofloxacin **98** was attempted (see Scheme 34) using the microwave conditions described previously (see 8.3), to see if the chloride produced better results compared with the bromide. However, as was seen with the other microwave reactions, a substantial amount of the disubstituted product **154** was seen by LCMS (in an approx 1:1 ratio with the desired product **155**).



Scheme 34: Attempted synthesis of the cyclopentanol-CipMe-(RR) conjugate **126**. a) NaI, DIPEA, acetonitrile, microwave reactor, 100 °C.

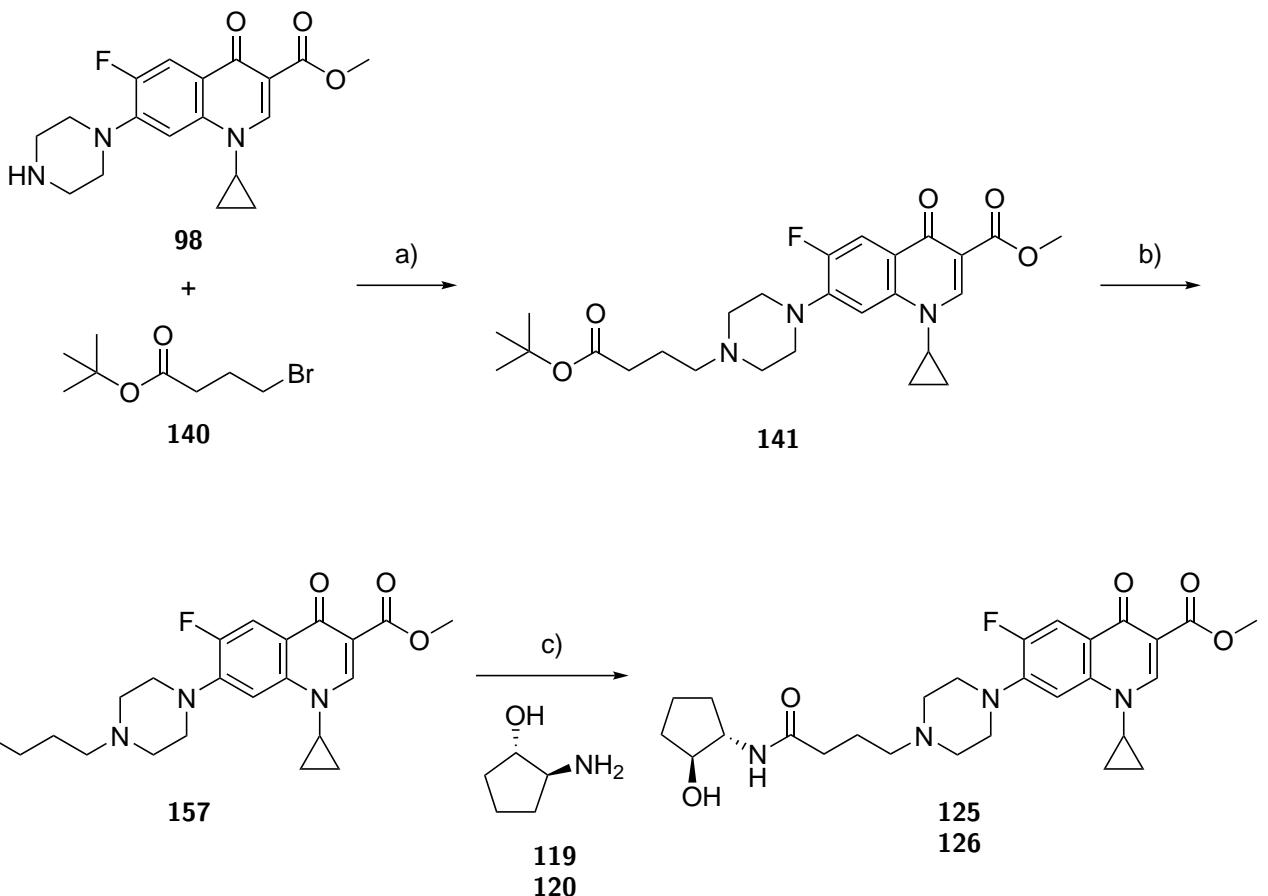
8.5.5 Synthesis of the cyclopentanol-CipMe conjugates **125** and **126** by peptide coupling

Given the side-reactions and low yields associated with the literature synthesis of the S_N2 conjugates proposed by Ganguly et. al,¹⁴⁵ an alternative synthesis was investigated, involving building up the linker on the ciprofloxacin side before coupling with the head group (see Scheme 35).



Scheme 35: Retrosynthesis of the cyclopentanol-CipMe conjugates **125** (*SS*) and **126** (*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 **140** methyl ciprofloxacin **98** (see Scheme 36). Intermediate **141** was obtained in acceptable yield after column chromatography (49.9 %). Intermediate **141** was deprotected in excellent yield using TFA in CH_2Cl_2 to give carboxylic acid **142**. 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 **142** was first coupled with (1*R*,2*R*)-2-aminocyclopentan-1-ol **120** using standard peptide coupling conditions to give cyclopentanol-CipMe conjugate **126**. Purification by column chromatography was attempted twice with poor results, before moving on to using preparative HPLC, which gave **126** cleanly in 38.7 % yield. Coupling was also performed with (1*S*,2*S*)-2-aminocyclopentan-1-ol **119** to give the enantiomer **125** in 54.7 % yield.



Scheme 36: Synthesis of the cyclopentanol-CipMe conjugates **125** (*SS*) and **126** (*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, HOBr, DIPEA, DMF, r.t., 16 h, **125** (*SS*): 54.7 %, **126** (*RR*): 38.7 %.

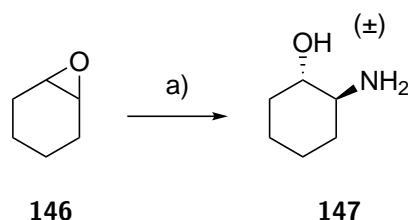
With (unfortunately not branching) routes to the S_N2 and click conjugates established (see 8.5.5 and 8.5.4 respectively), attention was turned to the cyclohexanol derivatives.

8.6 Cyclohexanol derivatives

8.6.1 Synthesis of the *trans*-2-aminocyclohexan-1-ol head group **147**

It was decided to produce the cyclohexanol conjugates racemically, with the option of re-synthesising enantiomerically pure versions via the route shown in 8.5.1 if the compounds showed biological activity.

Production of the cyclohexanol conjugates began with the synthesis of *trans*-2-aminocyclohexan-1-ol **147** (see Scheme 37), using a procedure reported by Xue *et al.*¹⁸⁸ Cyclohexene oxide **146** was opened using ammonia in water and methanol. Initially the reaction was carried out at 85 °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.

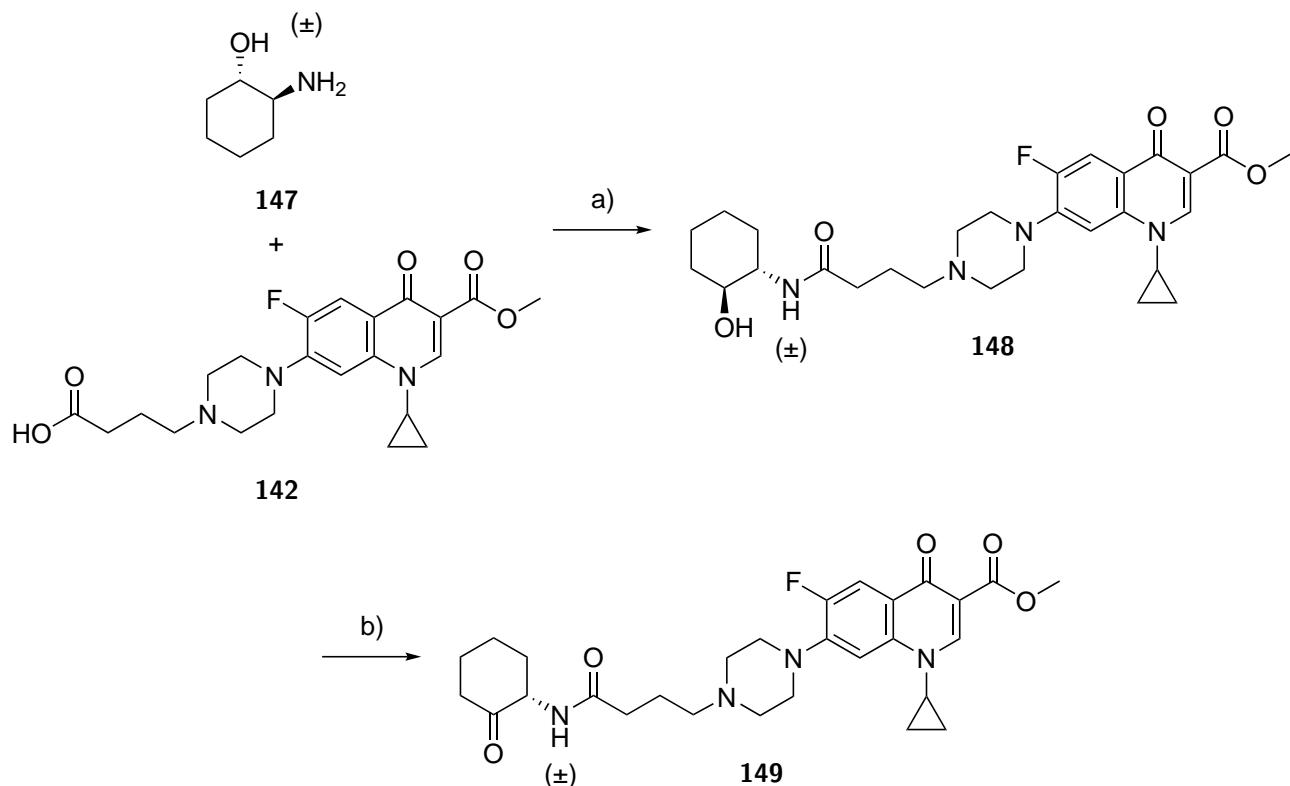


Scheme 37: Synthesis of *trans*-2-aminocyclohexan-1-ol **147**. a) NH_3 , water, MeOH , r.t., 72 h, 86.2 %.

8.6.2 Synthesis of the *trans*-cyclohexanol- and cyclohexanone-CipMe conjugates **148** and **149**

Carboxylic acid **142** was coupled with *trans*-2-aminocyclohexan-1-ol **147** using standard peptide coupling conditions to give *trans*-cyclohexanol-CipMe conjugate **148** in 31.7 % yield.

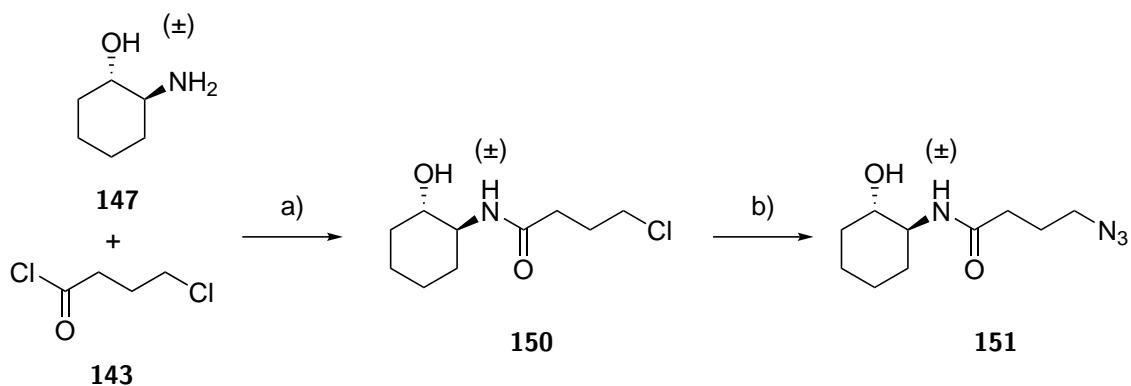
A portion of the *trans*-cyclohexanol-CipMe conjugate **148** was then oxidised to the ketone using Dess-Martin periodinane and the product was isolated in good yield.



Scheme 38: Synthesis of the cyclohexanol-CipMe conjugate **148** and the cyclohexanone-CipMe conjugate **149**. a) EDC, HOEt, DIPEA, DMF, r.t., 16 h, 31.7 %. b) DMP, CH_2Cl_2 , r.t., 6 h, 69.1 %.

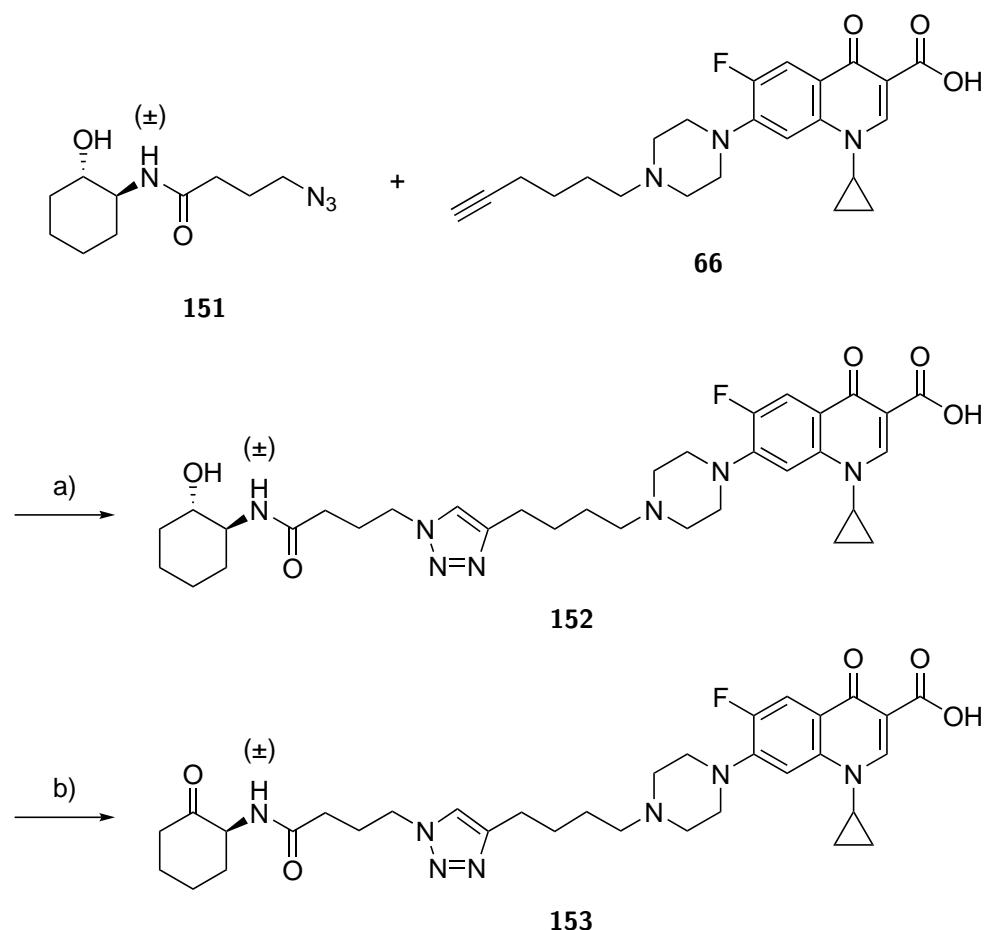
8.6.3 Synthesis of the *trans*-cyclohexanol- and cyclohexanone-Cip triazole conjugates **152** and **153**

The triazole conjugates were synthesised using the route described in 8.5.4. Cl-C₄-*trans*-cyclohexanol **150** was synthesised in good yield from *trans*-2-aminocyclohexan-1-ol **147** and 4-chlorobutyryl chloride **143**. Cl-C₄-*trans*-cyclohexanol **150** was then converted to N₃-C₄-*trans*-cyclohexanol **151** by reaction with sodium azide in excellent yield.



Scheme 39: Synthesis of *N*3-C4-*trans*-cyclohexanol **151**. a) TEA, CH₂Cl₂, 0 °C, 30 min, 76.1 %. b) NaN₃, acetonitrile, 50 °C, 16 h, 97.5 %.

The *trans*-cyclohexanol-Cip triazole conjugate **152** was synthesised using standard click conditions (see 9.25) in 48.9 % yield. A portion of the *trans*-cyclohexanol-Cip triazole conjugate **152** was then oxidised to the ketone using the same conditions used for the cyclohexanone-CipMe conjugate (see 8.6.2) in very good yield.



Scheme 40: Synthesis of the *trans*-cyclohexanol-Cip triazole conjugate **152** and the cyclohexanone-Cip triazole conjugate **153**. a) CuSO₄, THPTA, sodium ascorbate, H₂O, *t*-BuOH, r.t., 16 h, 48.9 %. b) DMP, CH₂Cl₂, r.t., 4 h, 78.0 %.

9 Experimental

9.1 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 acetonitrile 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 Keiselgel 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 Keiselgel 60 silica gel (230-400 mesh) or using a CombiFlash® EZ Prep with RediSep® normal-phase silica flash columns. Preparative high-performance liquid chromatography (HPLC) 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.¹⁸⁹ 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.¹⁸⁹ 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>).

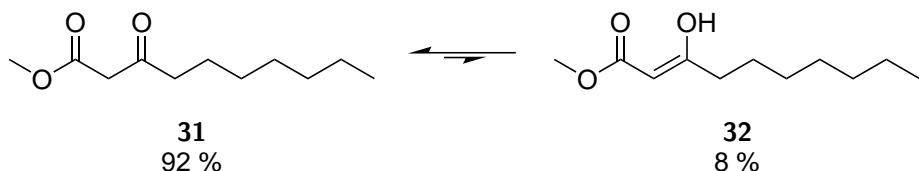
High resolution mass spectrometry (HRMS) data were recorded using a Micromass LCT Premier spectrometer or a Waters Vion IMS-QTOF spectrometer and reported mass values are within ± 5 ppm mass units. Liquid chromatography–mass spectrometry (LCMS) data were recorded on an Agilent 1200 series LC with an ESCi Multi-Mode Ionisation Waters ZQ spectrometer or a Waters ACQUITY H-Class UPLC with an ESCi Multi-Mode Ionisation Waters SQD2 mass spectrometer.

Infrared (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.

9.2 Methyl 3-oxodecanoate 31



Meldrum's acid **29** (9.00 g, 63.0 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 **30** (11.7 ml, 69.0 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 **31** and **32** was obtained as a colourless oil (8.34 g, 41.6 mmol, 66 %. 92 % **31** as determined by ^1H NMR).

Keto form 31

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 32

TLC R_f = 0.12 (5 % EtO_2/PE)

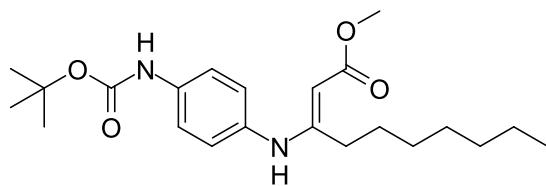
IR (neat) ν_{max} / cm^{-1} = 2927.8 (C-H), 2856.3 (C-H), 1653.8 (C=C), 1629.2 (α,β unsaturated C=O)

^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.^{165,166}

9.3 Methyl (E)-3-((4-((*tert*-butoxycarbonyl)amino)phenyl)amino)dec-2-enoate 34



Methyl 3-oxodecanoate **31** (500 mg, 2.50 mmol, 1.00 eq.) and *O*-*tert*-butyl *N*-(4-aminophenyl)carbamate **33** (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.). **34** 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)

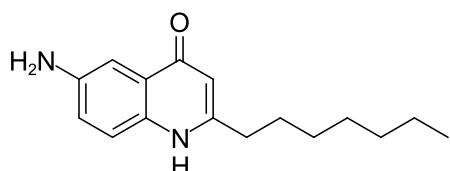
¹H NMR (400 MHz, CDCl₃) δ / ppm = 10.16 (s, 1 H, NHC(C₇H₁₅)=C), 7.35 (d, J = 8.6 Hz, 2 H, *meta* to NHBoc), 7.02 (d, J = 8.7 Hz, 2 H, *meta* to enamine), 6.60 (br s, 1 H, NHBoc), 4.71 (s, 1 H, C=CHC), 3.70 (s, 3 H, OCH₃), 2.23 (t, J = 7.7 Hz, 2 H, CH₂CH₂CH₂CH₂CH₂CH₂CH₃), 1.54 (s, 9 H, C(CH₃)₃), 1.40 (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.¹⁶¹

9.4 6-Amino-2-heptylquinolin-4-ol 35



Methyl (E)-3-((4-((*tert*-butoxycarbonyl)amino)phenyl)amino)dec-2-enoate **34** (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. **35** 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)

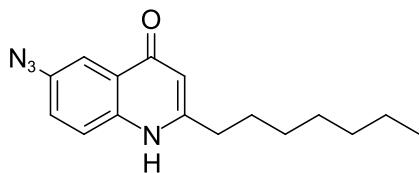
¹H NMR (400 MHz, DMSO-d₆) δ / ppm = 7.26 (d, J = 8.7 Hz, 1 H, *meta* to NH₂), 7.15 (d, J = 2.6 Hz, 1 H, *ortho* to C(=O)), 6.95 (dd, J = 2.7, 8.8 Hz, 1 H, *para* to C(=O)), 5.74 (s, 1 H, *ortho* to CH₂), 5.16 (s, 2 H, NH₂), 2.52 (t, J = 7.4 Hz, 2 H, CCH₂), 1.64 (quin, J = 7.6 Hz, 2 H, CCH₂CH₂), 1.36 - 1.19 (m, 8 H, CH₂CH₂CH₂CH₂CH₃), 0.86 (t, J = 7.0 Hz, 3 H, H₃)

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.¹⁶¹

9.5 6-Azido-2-heptylquinolin-4-ol **36**



6-Amino-2-heptylquinolin-4-ol **35** (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. **36** 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)

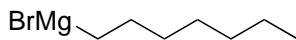
¹³C NMR (101 MHz, MeOD) δ / ppm = 172.3 (C(=O)), 155.5 (NH₂CH₂), 137.4 (CN₃), 135.6 (*para* to N₃), 124.6 (*para* to C(=O)), 124.1 (*ipso* to C(=O)), 120.7 (*meta* to N₃ and *meta* to C(=O)), 112.8 (*ortho* to N₃ and *ortho* to C(=O)), 107.0 (C(=O)CH), 33.3 (NH₂CH₂CH₂CH₃), 31.2 (CH₂CH₂CH₃), 28.3 - 28.5 (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.¹⁶¹

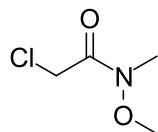
????

9.6 Heptyl magnesium bromide 38



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 **37** (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 **38** was obtained as a pale grey suspension (15 ml, ~1 M) which was used without further purification.

9.7 2-Chloro-*N*-methoxy-*N*-methylacetamide 41



N,O-Dimethylhydroxyl amine hydrochloride **39** (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 **40** (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. **41** was obtained as white, prism-like crystals (7.24 g, 52.6 mmol, 71 %).

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

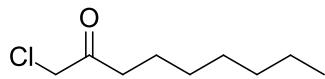
IR (neat) ν_{max} / cm^{-1} = 3016.7 (C-H), 2966.4 (C-H), 2946.7 (C-H), 2827.7 (C-H), 1666.2 (C=O)

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.⁹³

9.8 1-Chlorononan-2-one 42



2-Chloro-*N*-methoxy-*N*-methylacetamide **41** (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 **38** (~ 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. **42** was obtained as a colourless oil (1.23 g, 6.96 mmol, 96 %).

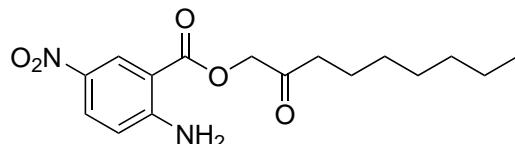
IR (neat) ν_{max} / cm⁻¹ = 2951.7 (C-H), 2925.0 (C-H), 2855.5 (C-H), 1720.4 (C=O)

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.⁹³

9.9 2-Oxononyl 2-amino-5-nitrobenzoate **44**



5-Nitroanthranilic acid **43** (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 **42** (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. **44** 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)

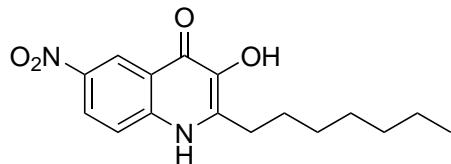
¹H NMR (400 MHz, DMSO-d₆) δ / ppm = 8.66 (d, J = 2.8 Hz, 1 H, *ortho* to C(=O)), 8.12 (dd, J = 2.8, 9.4 Hz, 1 H, *para* to C(=O)), 6.93 (d, J = 9.4 Hz, 1 H, *meta* to C(=O)), 5.05 (s, 2 H, OCH₂C(=O)), 2.49 (t, J = 7.4 Hz, 2 H, C(=O)CH₂CH₂), 1.52 (quin, J = 7.2 Hz, 2 H, C(=O)CH₂CH₂), 1.32 - 1.20 (m, 8 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.¹⁶¹

9.10 6-Nitro-2-heptyl-3-hydroxyquinolin-4(1H)-one 45



2-Oxononyl 2-amino-5-nitrobenzoate **44** (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. **45** 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)

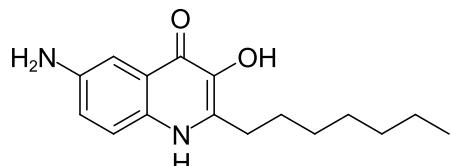
¹H NMR (400 MHz, DMSO-d₆) δ / ppm = 12.00 (s, 1 H, NH), 8.91 (d, *J* = 2.8 Hz, 1 H, *ortho* to C=O), 8.29 (dd, *J* = 2.7, 9.2 Hz, 1 H, *para* to C=O), 7.70 (d, *J* = 9.3 Hz, 1 H, *meta* to C=O), 2.75 (t, *J* = 7.7 Hz, 2 H, CCH₂), 1.67 (quin, *J* = 7.3 Hz, 2 H, CCH₂CH₂), 1.36 - 1.23 (m, 8 H, CH₂CH₂CH₂CH₂CH₃), 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.¹⁶¹

9.11 6-Amino-2-heptyl-3-hydroxyquinolin-4(1H)-one 46



6-Nitro-2-heptyl-3-hydroxyquinolin-4(1H)-one **45** (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. **46** was obtained as a yellow-brown amorphous solid (14.5 mg, 0.0529 mmol, 80 %).

mp (MeOH) T / °C = 176

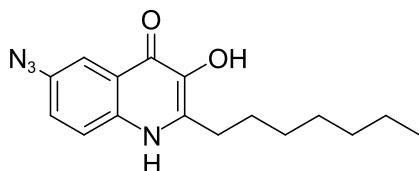
IR (neat) ν_{max} / cm⁻¹ = 3000.00 (O-H, br) 2925.41 (C-H), 2854.09 (C-H), 1613.43 (C=O)

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.¹⁶¹ It is possible that Baker's product is a Zn adduct.

9.12 6-Azido-2-heptyl-3-hydroxyquinolin-4(1H)-one 47



6-Amino-2-heptyl-3-hydroxyquinolin-4(1H)-one **46** (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. **47** 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

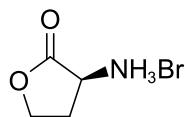
don't have?

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

try?

Spectroscopic data are consistent with the literature.¹⁶¹

9.13 (S)-3-Aminodihydrofuran-2(3H)-one hydrobromide 50



L-Methionine **48** (3.04 g, 20.4 mmol, 1 eq.) and bromoacetic acid **49** (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. **50** 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)

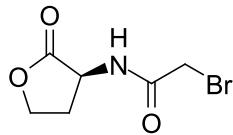
¹H NMR (400 MHz, DMSO-d₆) δ / ppm = 8.59 (br s, 3 H, NH₃⁺), 4.46 (dt, *J* = 1.3, 8.9 Hz, 1 H, OCHH), 4.37 (dd, *J* = 8.8, 11.4 Hz, 1 H, CHNH₃⁺), 4.29 (ddd, *J* = 6.1, 8.8, 10.9 Hz, 1 H, OCHH), 2.57 (dddd, *J* = 1.2, 6.1, 8.9, 12.3 Hz, 1 H, OCH₂CHH), 2.26 (dtd, *J* = 9.0, 11.2, 12.2 Hz, 1 H, OCH₂CHH)

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.¹⁶²

9.14 (S)-2-Bromo-N-(2-oxotetrahydrofuran-3-yl)acetamide 52



(*S*)-3-Aminodihydrofuran-2(3H)-one hydrobromide **50** (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 **51** (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. **52** 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, CDCl_3) 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, OCH_2CHH), 2.22 (dtd, J = 12.6, 11.5, 11.5, 8.9 Hz, 1 H, OCH_2CHH)

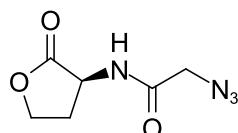
^{13}C NMR (101 MHz, CDCl_3) δ / ppm = 174.6 (OC=O), 166.4 (C(=O)NH), 66.1 (OCH_2), 49.8 (CHNHC=O), 29.9 (OCH_2CH_2), 28.2 (O=CCH_2Br)

HRMS The compound does not ionise.

$[\alpha]_D^{20} / {}^\circ\text{10}^{-1}\text{cm}^2\text{g}^{-1} = 27.0$, lit. = 20.5 ($c / \text{g}(100 \text{ ml})^{-1} = 0.00740$, CHCl_3)

The data are consistent with the literature.^{162, 190}

9.15 (*S*)-2-Azido-*N*-(2-oxotetrahydrofuran-3-yl)acetamide 53



(3*S*)-2-Oxotetrahydrofuran-3-aminium bromide **50** (100 mg, 0.552 mmol, 1.08 eq.), NaN_3 (85.7 mg, 1.32 mmol, 2.61 eq.) and NaHCO_3 (84.9 mg, 1.01 mmol, 2.00 eq.) were dissolved in CH_2Cl_2 (2 ml) and H_2O (2 ml). Bromoacetyl bromide **51** (44.0 μL , 102 mg, 0.505 mmol, 1.00 eq.) was then added dropwise. The reaction mixture was stirred for 48 h, after which the CH_2Cl_2 was removed under vacuum. The aqueous phase was extracted with EtOAc (4 \times 10 ml). The combined organic layers were dried with MgSO_4 and the solvent was removed under reduced pressure. **53** was obtained as white, needle-like crystals (38.4 mg, 0.209 mmol, 41 %).

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

IR (neat) $\nu_{max} / \text{cm}^{-1} = 3283.5$ (N-H), 2923.3 (C-H), 2853.0 (C-H), 2129.7 (N_3), 1782.9 (lactone C=O), 1661.4 (amide C=O), 1536.8 (N-H bend)

^1H NMR (400 MHz, CDCl_3) 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, CH_2N_3), 2.76 (dddd, J = 12.5, 8.8, 6.0, 1.4 Hz, 1 H, OCH_2CHH), 2.25 (dtd, J = 12.5, 11.4, 11.4, 8.9 Hz, 1 H, OCH_2CHH)

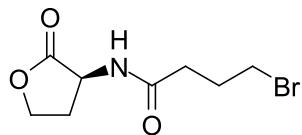
^{13}C NMR (101 MHz, CDCl_3) δ / ppm = 174.9 (OC=O), 167.5 (C(=ONH), 66.0 (OCH_2), 52.2 (O=CCH_2N_3), 48.9 (CHNHC=O), 29.7 (OCH_2CH_2)

HRMS The compound does not ionise.

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

The data are consistent with the literature.¹⁶²

9.16 (*S*)-4-Bromo-*N*-(2-oxotetrahydrofuran-3-yl)butanamide 55



(*S*)-3-Aminodihydrofuran-2(*3H*)-one hydrobromide **50** (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 **54** (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. **55** 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)

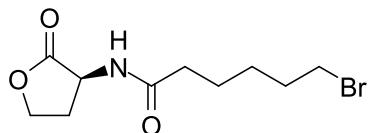
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 175.4 (OC=O), 172.3 (C(=O)NH), 66.1 (OCH₂), 49.3 (CHNHC=O), 33.9 (C(=O)CH₂), 33.1 (CH₂Br), 30.3 (OCH₂CH₂), 27.9 (C(=O)CH₂CH₂)

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.

9.17 (*S*)-6-Bromo-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide 58



(*S*)-3-Aminodihydrofuran-2(*3H*)-one hydrobromide **50** (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 **57** (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. **58** 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)

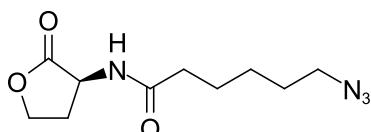
$^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ / ppm = 175.5 (OC=O), 173.3 (C(=O)NH), 66.1 (OCH₂), 49.3 (CHNHC=O), 35.8 (CH₂Br), 33.5 (C(=O)CH₂), 32.3 (CH₂CH₂Br), 30.5 (OCH₂CH₂), 27.6 (C(=O)CH₂CH₂), 24.4 (C(=O)CH₂CH₂CH₂)

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.

9.18 (*S*)-6-Azido-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide 59



(*S*)-6-Bromo-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide **58** (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. **59** 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.

9.19 Hex-5-ynal 61



Pyridinium chlorochromate (14.6 g, 68.1 mmol, 1.50 eq) and CH₂Cl₂ (500 ml) were stirred at r.t. under argon. 5-Hexyn-1-ol **60** (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. **61** was obtained as a pale yellow-green oil (4.72 g, 49.1 mmol, 72 %).

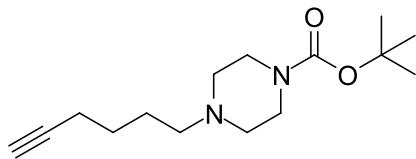
IR (neat) $\nu_{max} / \text{cm}^{-1} = 3292.7$ (alkyne C-H), 2943.3 (alkane C-H), 2830.9 (aldehyde C-H), 2728.6 (aldehyde C-H), 1720.3 (aldehyde C=O)

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.¹⁷³

9.20 *tert*-Butyl 4-(hex-5-yn-1-yl)piperazine-1-carboxylate 63



Hex-5-ynal **61** (0.407 g, 4.24 mmol, 1.00 eq.) and *tert*-butyl piperazine-1-carboxylate **62** (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. **63** 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)

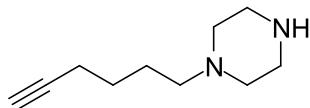
¹H NMR (400 MHz, CDCl₃) δ / ppm = 3.44 (t, J = 5.2 Hz, 4 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.39 (t, J = 5.1 Hz, 4 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂), 2.37 (t, J = 7.3 Hz, 2 H, CH₂CH₂CH₂N), 2.23 (dt, J = 2.7, 6.8 Hz, 2 H, HC≡CCH₂), 1.96 (t, J = 2.7 Hz, 1 H, HC≡C), 1.65 - 1.53 (m, 4 H, HC≡CCH₂CH₂CH₂), 1.47 (s, 9 H,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

9.21 1-(Hex-5-yn-1-yl)piperazine 64



tert-Butyl 4-(hex-5-yn-1-yl)piperazine-1-carboxylate **63** (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). **64** 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)

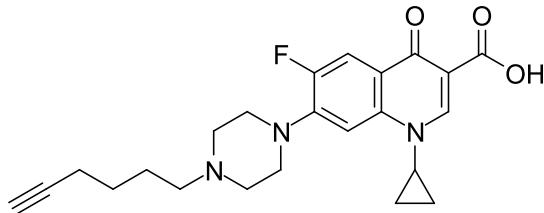
¹H NMR (400 MHz, CDCl₃) δ / ppm = 2.88 (t, J = 4.9 Hz, 4 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.39 (m, 4 H, CH₂CH₂CH₂N(CH₂)CH₂), 2.31 (t, J = 7.1 Hz, 2 H, HC≡CCH₂CH₂CH₂N), 2.20 (dt, J = 2.7, 6.8 Hz, 2 H, HC≡CCH₂), 2.05 (br s, 1 H, NH), 1.93 (t, J = 2.7 Hz, 1 H, HC≡C), 1.65 - 1.48 (m, 4 H, HC≡CCH₂CH₂CH₂N)

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.

9.22 1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydro-quinoline-3-carboxylic acid 66



7-Chloro-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquino-line-3-carboxylic acid **65** (1.27 g, 4.51 mmol, 1 eq.), 1-(hex-5-yn-1-yl)piperazine **64** (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). **66** 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)

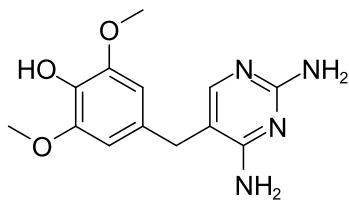
¹³C NMR (126 MHz, DMSO-d₆) δ / ppm = 176.4 (C(=O)CC(=O)OH), 165.8 (C(=O)OH), 152.8 (d, J = 248.5 Hz, *ipso* to F), 148.2 (CHCC(=O)OH), 143.7 (d, J = 11.1 Hz, *para* to C(=O)), 139.1 (*para* to F), 119.4 (d, J = 6.9 Hz, *ipso* to C(=O)), 111.2 (d, J = 22.5 Hz, *ortho* to F and *ortho* to C(=O)), 106.9 (*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 (CH₂CH₂CH₂N), 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.

9.23 4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenol 67



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. **67** 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)

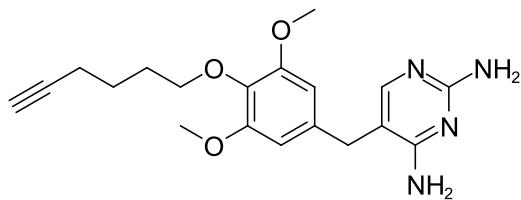
¹H NMR (400 MHz, MeOD) δ / ppm = 7.21 (s, 1 H, CHN), 6.54 (s, 2 H, *meta* to OCH₂), 4.87 (br s, 5 H, OH, NH₂ × 2), 3.82 (s, 6 H, OCH₃), 3.63 (s, 2 H, CCH₂C)

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.¹⁶⁴

9.24 5-(4-(Hex-5-yn-1-yloxy)-3,5-dimethoxybenzyl)pyrimidine-2,4-diamine 69



4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenol **67** (1.00 g, 3.62 mmol, 1 eq.), 6-chloro-1-hexyne **68** (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). **69** 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)

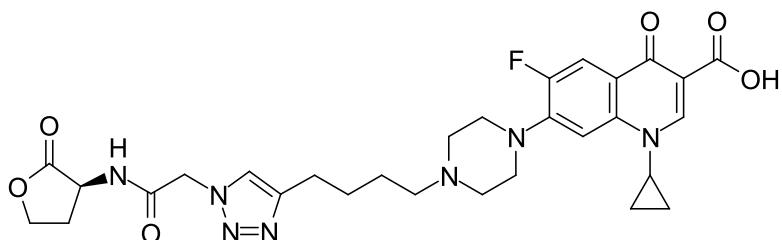
HRMS (ESI⁺) m/z / Da = 357.1920, [M+H]⁺ found, [C₁₉H₂₅N₄O₃]⁺ requires 357.1927

The compound has not been reported previously.

9.25 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 **72** 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).

9.26 (*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 **70**



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 **66** (20.6 mg, 50.0 μ mol, 1 eq.) and (*S*)-2-azido-*N*-(2-oxotetrahydrofuran-3-yl)acetamide **53** (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. **70** 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=CCH₂), 7.57 (d, *J* = 7.6 Hz, 1 H, *meta* to F), 5.13 (s, 1 H, C(=O)CHHN), 5.12 (s, 1 H, C(=O)CHHN), 4.64 (ddd, *J* = 10.9, 9.0, 7.8 Hz, 1 H, CHNH), 4.36 (td, *J* = 8.9, 1.7 Hz, 1 H, OCHH), 4.23 (ddd, *J* = 10.6, 8.8, 6.4 Hz, 1 H, OCHH), 3.83 (tt, *J* = 7.0, 4.0 Hz, 1 H, NCH(CH₂)₂), 3.32 (br s, 4 H, CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 2.67 (t, *J* = 7.4 Hz, 2 H, CH=CCH₂), 2.58 (br t, *J* = 5.0 Hz, 4 H, CH₂CH₂CH₂N(CH₂)CH₂), 2.42 - 2.49 (m, 1 H, OCH₂CHH), 2.40 (t, *J* = 7.1 Hz, 2 H, CH=CCH₂CH₂CH₂CH₂), 2.17 (dtd, *J* = 11.7, 10.8, 9.0 Hz, 1 H, OCH₂CHH), 1.66 (quin, *J* = 7.2 Hz, 2 H, CH=CCH₂CH₂), 1.53 (quin, *J* = 7.2 Hz, 2 H, CH=CCH₂CH₂CH₂), 1.28 - 1.35 (m, 2 H, NCH(CHH)₂), 1.16 - 1.21 (m, 2 H, NCH(CHH)₂)

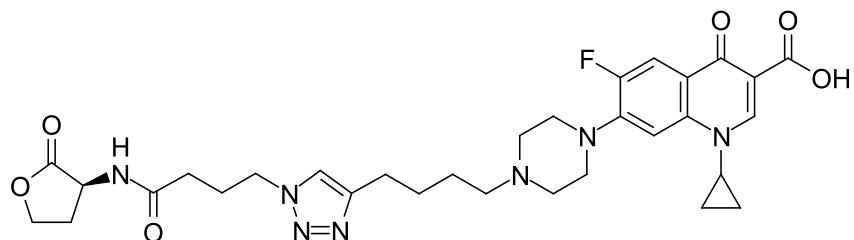
¹³C NMR (101 MHz, DMSO d₆) δ / ppm = 176.4 (C(=O)CC(=O)OH), 174.9 (OC(=O)), 166.0 (C(=O)OH), 165.9 (NHC(=O)), 153.1 (d, *J* = 250.8 Hz, *ipso* to F), 148.0 (CH=CC(=O)OH), 146.6 (CH=CCH₂), 145.3 (d, *J* = 9.6 Hz, *ipso* to piperazine), 139.2 (*para* to F), 123.4 (CH=CCH₂), 118.5 (d, *J* = 7.5 Hz, *para* 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=CCH₂CH₂CH₂CH₂N), 52.4 (CH₂CH₂CH₂N(CH₂)CH₂), 51.2 (C(=O)CH₂N), 49.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 49.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂CH₂), 48.2 (CHNH), 35.9 (NCH(CH₂)₂), 28.2 (CH₂CHNH), 26.8 (CH=CCH₂CH₂), 25.7 (CH=CCH₂CH₂CH₂), 24.9 (CH=CCH₂), 7.6 (NCH(CH₂)₂)

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.

9.27 (*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 **75**



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 **66** (20.6 mg, 50.0 μ mol, 1 eq.) and (*S*)-4-azido-*N*-(2-oxotetrahydrofuran-3-yl)butanamide **56** (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. **75** 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)

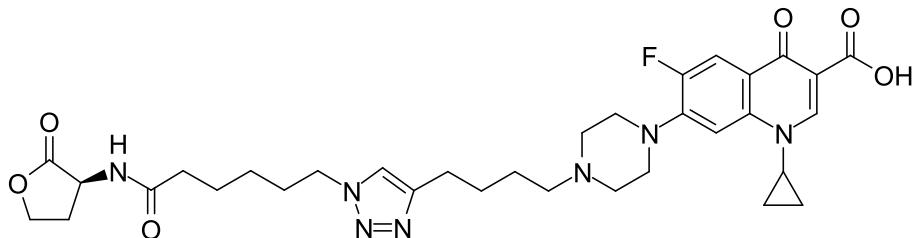
¹³C NMR (126 MHz, DMSO d₆) δ / ppm = 176.3 (C(=O)CC(=O)OH), 175.4 (OC(=O)), 171.2 (NHC(=O)), 166.0 (C(=O)OH), 153.0 (d, *J* = 248.6 Hz, *ortho* to F), 148.0 (CH=CC(=O)OH), 146.8 (CH=CCH₂), 145.2 (d, *J* = 9.6 Hz, *ipso* to piperazine), 139.2 (*para* to F), 121.7 (CH=CCH₂), 118.5 (d, *J* = 7.5 Hz, *para* 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.

9.28 (*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 76



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 **66** (20.6 mg, 50.0 μ mol, 1 eq.) and (*S*)-6-azido-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide **59** (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. **76** 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

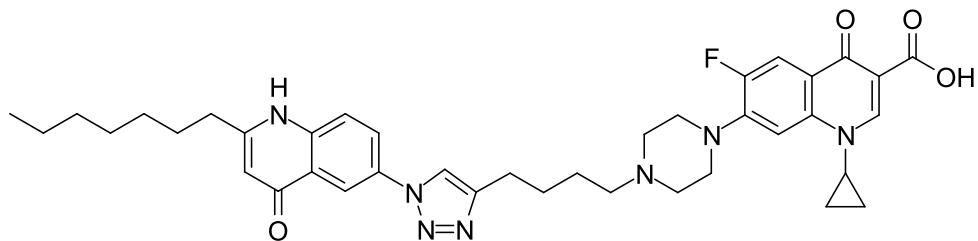
CH_2CH_2), 25.7 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2$), 25.4 ($\text{NHC}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2$), 24.9 ($\text{CH}=\text{CCH}_2$), 24.5 ($\text{NHC}(=\text{O})\text{CH}_2\text{CH}_2$), 7.6 ($\text{NCH}(\text{CH}_2)_2$)

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.

9.29 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 78



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 **66** (4.1 mg, 10.0 μmol , 1 eq.) and 6-azido-2-heptylquinolin-4(1*H*)-one **36** (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. **78** 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, $\text{NCH}=\text{CCH}_2$), 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, $\text{NHC}=\text{CHC}(=\text{O})$), 3.85 (tt, $J = 7.0, 4.0$ Hz, 1 H, $\text{NCH}(\text{CH}_2)_2$), 3.23 - 3.30 (m, 10 H, $\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)\text{CH}_2\text{CH}_2$), 2.82 (t, $J = 5.9$ Hz, 2 H, $\text{NCH}=\text{CCH}_2$), 2.63 (t, $J = 7.9$ Hz, 2 H, $\text{CH}_2\text{C}=\text{CHC}(=\text{O})$), 1.76 - 1.81 (m, 4 H, $\text{NCH}=\text{CCH}_2\text{CH}_2\text{CH}_2$), 1.70 (quin, $J = 7.2$ Hz, 2 H, $\text{CH}_2\text{CH}_2\text{C}=\text{CHC}(=\text{O})$), 1.15 - 1.38 (m, 12 H, $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2$, $\text{NCH}(\text{CHH})_2$ and $\text{NCH}(\text{CHH})_2$), 0.87 (t, $J = 6.9$ Hz, 3 H, CH_3)

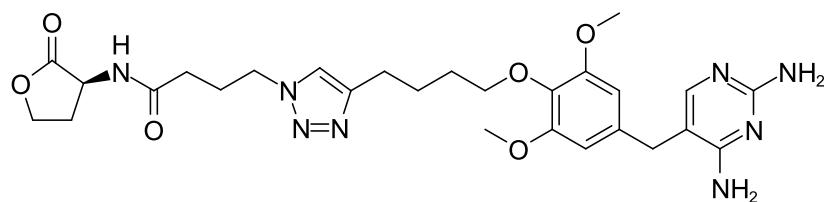
¹³C NMR (126 MHz, DMSO d₆) δ / ppm = 176.4 ($\text{C}(=\text{O})\text{CC}(=\text{O})\text{OH}$), 176.3 ($\text{CHC}(=\text{O})$), 165.8 ($\text{C}(=\text{O})\text{OH}$), 154.3 ($\text{CCHC}(=\text{O})$), 152.9 (d, $J = 240.1$ Hz, *ipso* to F), 148.3 ($\text{CH}=\text{CC}(=\text{O})\text{OH}$), 147.5 (NCHCCH_2), 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.

9.30 (*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 82



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 **69** (20.6 mg, 50.0 μ mol, 1 eq.) and (*S*)-4-azido-*N*-(2-oxotetrahydrofuran-3-yl)butanamide **56** (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 **56** (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. **82** 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

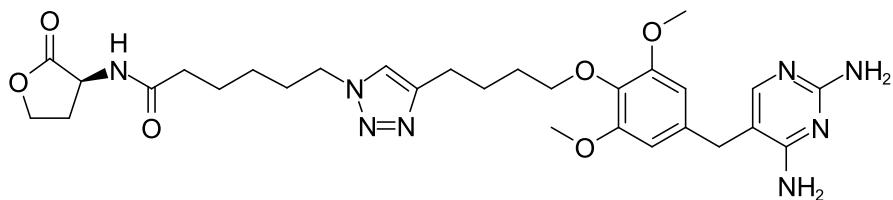
(br s, $\underline{\text{NC}}(\text{NH}_2)\text{N}$), 153.2 (*ipso* to OCH_3), 150.5 (br s, $\underline{\text{CH}}\text{NC}(\text{NH}_2)\text{N}$), 147.3 ($\text{NCH}=\underline{\text{CCH}_2\text{CH}_2}$), 135.2 (*para* to CH_2O), 135.0 (*ipso* to CH_2O), 122.1 ($\underline{\text{CH}}=\text{CCH}_2\text{CH}_2$), 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.

9.31 (*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 83



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 **69** (20.6 mg, 50.0 μmol , 1 eq.) and (*S*)-6-azido-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide **59** (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 **59** (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 (6×10 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. **83** 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, $\text{C}=(\text{O})\underline{\text{CH}_2\text{CH}_2\text{CH}_2}$)

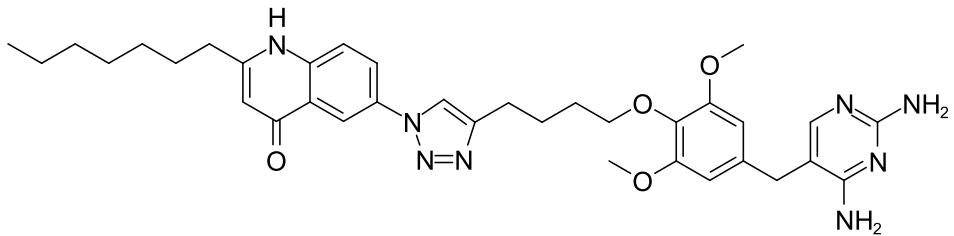
¹³C NMR (125 MHz, DMSO d₆) δ / ppm = 175.4 (OC=O), 172.0 (NHC=O), 162.2 (CC(NH₂)N), 161.8 (NC(NH₂)N), 154.8 (CHNC(NH₂)N), 152.8 (*ipso* to OCH₃), 146.7 (CH=CCH₂CH₂), 135.5 (*para* to CH₂O), 134.8 (*ipso* to CH₂O), 121.6 (CH=CCH₂CH₂), 105.9 (CH₂CC(NH₂)=N), 105.8 (*meta* to CH₂O), 71.9 (CH₂CH₂CH₂O), 65.2 (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.

9.32 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 85



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 **69** (3.6 mg, 10.0 μmol , 1 eq.) and 6-azido-2-heptylquinolin-4(*1H*)-one **36** (2.8 mg, 10.0 μmol , 1 eq.). A similarly degassed solution of CuSO₄ · 5 H₂O (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 water (10 μl) 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. **85** was obtained as a clear gum (2.6 mg, 4.1 μmol , 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)

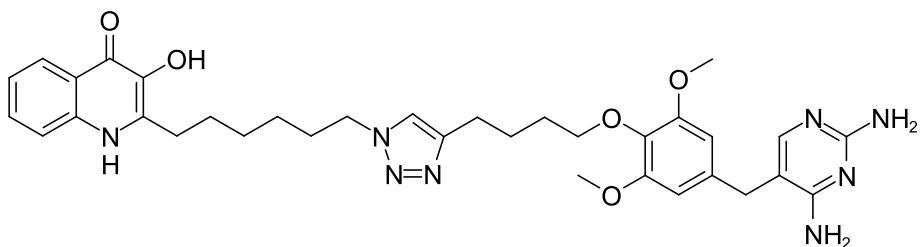
¹H NMR (500 MHz, DMSO d₆) δ / ppm = 11.80 (s, 1 H, NH), 8.69 (s, 1 H, NCH=CCH₂), 8.41 (d, *J* = 2.7 Hz, 1 H, *ortho* to C=O), 8.17 (dd, *J* = 9.0, 2.6 Hz, 1 H, *para* to C=O), 7.73 (d, *J* = 9.0 Hz, 1 H, *ortho* to NH), 7.51 (br s, 4 H, NH₂), 7.41 (s, 1 H, CHN=CNH₂), 6.61 (s, 2 H, *meta* to CH₂), 6.02 (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.

9.33 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 87



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 **69** (14.2 mg, 39.8 μmol, 1 eq.) and 2-(6-azidohexyl)-3-hydroxyquinolin-4(1*H*)-one **28** (11.4 mg, 39.8 μmol, 1 eq.). A similarly degassed solution of CuSO₄ · 5 H₂O (1.25 mg, 5 μmol, 0.125 eq. 50 mM), THPTA (2.18 mg, 5 μmol, 0.125 eq. 50 mM) and sodium ascorbate (1.98 mg, 10 μmol, 0.25 eq., 100 mM) in water (100 μl) 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. **87** was obtained as a pale brown amorphous solid (4.7 mg, 7.3 μmol, 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)

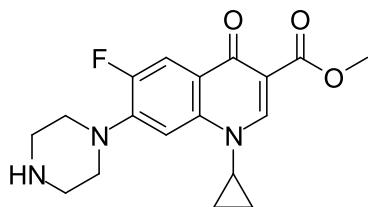
¹³C NMR (125 MHz, DMSO d₆) δ / ppm = 168.9 (C=O), 162.5 (CC(NH₂)N), 162.5 (NC(NH₂)N), 152.9 (CHNC(NH₂)N), 152.8 (*ipso* to OCH₃), 146.8 (CH=CCH₂CH₂), 137.7 (COH), 137.3 (*para* to OH), 135.4

(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.

9.34 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 98



Ciprofloxacin **24** (10.0 g, 30 mmol, 1 eq.) and *para*-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. **98** 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)

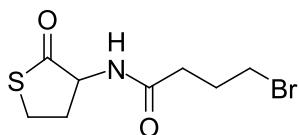
¹³C NMR (101 MHz, MeOD) δ / ppm = 175.2 (C(=O)CC(=O)OCH₃), 166.8 (C(=O)OCH₃), 154.9 (d, *J* = 248.0 Hz, *ipso* to F), 150.1 (C=CC(=O)OCH₃), 146.6 (d, *J* = 10.4 Hz, *ipso* to piperazine), 139.9 (*para* to F), 123.3 (d, *J* = 6.9 Hz, *para* to piperazine), 113.0 (d, *J* = 23.4 Hz, *ortho* to C=O and *ortho* 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.¹⁷⁷

9.35 4-Bromo-*N*-(2-oxotetrahydrothiophen-3-yl)butanamide 100



3-Aminodihydrothiophen-2(3*H*)-one hydrochloride **99** (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 **54** (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. **100** 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)

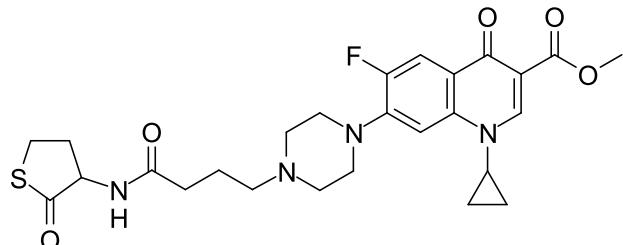
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 205.4 (SC(=O)), 172.1 (NHC(=O)), 59.4 (CHNH), 34.1 (C(=O)CH₂), 33.1 (CH₂Br), 31.8 (SCH₂CH₂), 28.0 (C(=O)CH₂CH₂), 27.5 (SCH₂)

HRMS (ESI⁺) The compound does not ionise.

The compound has been synthesised previously^{145, 146} but characterisation was not published.

works
in
LCMS
see
Lois283

9.36 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 101



Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate **98** (50 mg, 0.145 mmol, 1 eq.), 4-bromo-*N*-(2-oxotetrahydrothiophen-3-yl)butanamide **100** (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 **100** (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). **101** 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)

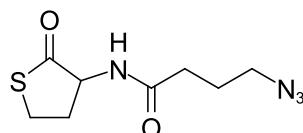
¹³C NMR (126 MHz, MeOD) δ / ppm = 207.0 (SC(=O)), 175.7 (NHC(=O)), 175.1 (C(=O)CC(=O)OCH₃), 166.6 (C(=O)OCH₃), 154.7 (d, J = 249.0 Hz, *ipso* to F), 150.2 (s, CH=CC(=O)OCH₃), 145.6 (d, J = 10.6 Hz, *ipso* to piperazine), 139.8 (*para* to F), 123.5 (d, J = 6.9 Hz, *para* to piperazine), 113.1 (d, J = 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.^{145, 146} Only HRMS characterisation was published, and this agrees with the result above.

9.37 4-Azido-N-(2-oxotetrahydrothiophen-3-yl)butanamide 102



4-Bromo-N-(2-oxotetrahydrothiophen-3-yl)butanamide **100** (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. **102** 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)

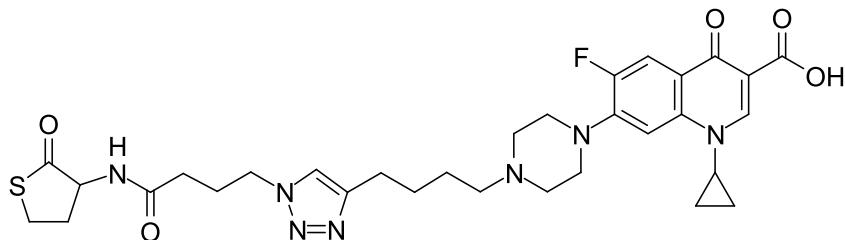
¹H NMR (400 MHz, CDCl₃) δ / ppm = 6.71 (d, J = 7.3 Hz, 1 H, NH), 4.54 (dt, J = 13.0, 7.0 Hz, 1 H, CHNH), 3.30 (t, J = 6.7 Hz, 2 H, CH₂N₃), 3.31 (td, J = 11.7, 5.3 Hz, 1 H, SCHH), 3.19 (ddd, J = 11.3, 7.0, 1.2 Hz, 1 H, SCHH), 2.70 (dddd, J = 12.4, 6.8, 5.3, 1.2 Hz, 1 H, SCH₂CHH), 2.29 (t, J = 7.5 Hz, 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.

9.38 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 103



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **66** (15 mg, 36.7 μ mol, 1 eq.) and 4-azido-*N*-(2-oxotetrahydrothiophen-3-yl)butanamide **102** (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. **103** 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, $\text{NCH}(\text{CHH})_2$)

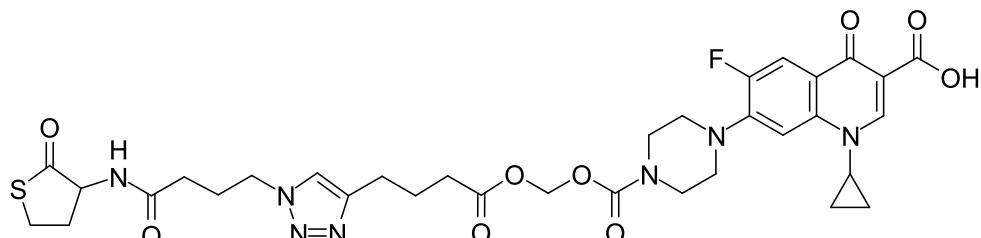
^{13}C NMR (126 MHz, DMSO d₆) δ / ppm = 205.6 ($\text{SC}(\text{=O})$), 176.4 ($\text{C}(\text{=O})\text{CC}(\text{=O})\text{OH}$), 171.4 ($\text{NHC}(\text{=O})$), 166.0 ($\text{C}(\text{=O})\text{OH}$), 153.1 (d, $J = 249.3$ Hz, *ortho* to F), 148.0 ($\text{CH}=\text{CC}(\text{=O})\text{OH}$), 146.9 ($\text{CH}=\text{CCH}_2$), 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.

9.39 1-Cyclopropyl-6-fluoro-4-oxo-7-((4-((4-((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 104



1-Cyclopropyl-6-fluoro-7-((4-((hex-5-ynoyloxy)methoxy)carbonyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **156** (203 mg, 0.407 mmol, 1 eq.), 4-azido-N-(2-oxotetrahydrothiophen-3-yl)butanamide **102** (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). **104** 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),

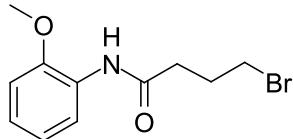
8.21 (d, $J = 8.5$ Hz, 1 H, NH), 7.89 (d, $J = 13.1$ Hz, 1 H, *ortho* to F), 7.85 (s, 1 H, CH=CCH₂), 7.57 (d, $J = 7.4$ Hz, 1 H, *meta* to F), 5.74 (s, 1 H, OCH₂O), 4.58 (ddd, $J = 12.6, 8.1, 7.2$ Hz, 1 H, CHNH), 4.30 (t, $J = 6.9$ Hz, 2 H, C(=O)CH₂CH₂CH₂N), 3.80 (tt, $J = 6.9, 3.6$ Hz, 1 H, NCH(CH₂)₂), 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.

9.40 4-Bromo-N-(2-methoxyphenyl)butanamide 106



2-Methoxyaniline **105** (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 **54** (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. **106** 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)

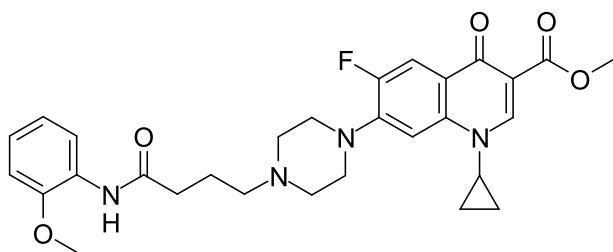
¹H NMR (400 MHz, CDCl₃ d₁) δ / ppm = 8.32 (dd, $J = 8.0, 1.7$ Hz, 1 H, *ortho* to NH), 7.85 (br s, 1 H, NH), 7.02 (td, $J = 7.9, 1.7$ Hz, 1 H, *para* to NH), 6.93 (td, $J = 7.7, 1.4$ Hz, 1 H, *para* to OCH₃), 6.85 (dd, $J = 8.1, 1.5$ Hz, 1 H, *ortho* to OCH₃), 3.85 (s, 3 H, CH₃), 3.50 (t, $J = 6.4$ Hz, 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.

9.41 Methyl 1-cyclopropyl-6-fluoro-7-(4-((2-methoxyphenyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 107



Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate **98** (500 mg, 1.45 mmol, 1 eq.), 4-bromo-*N*-(2-methoxyphenyl)butanamide **106** (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. **107** 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)

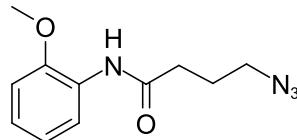
¹³C NMR (101 MHz, CDCl₃ d₁) δ / ppm = 172.9 (C(=O)CC(=O)OCH₃), 170.8 (NH₂C(=O)), 166.2 (C(=O)OCH₃), 153.3 (d, *J* = 248.0 Hz, *ipso* to F), 148.2 (C=CC(=O)OCH₃), 147.6 (*ipso* to OCH₃), 144.4 (d, *J* = 10.4 Hz, *ipso* to piperazine), 137.9 (*para* to F), 127.6 (*ipso* to NH), 123.4 (*para* to NH), 122.7 (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.

9.42 4-Azido-*N*-(2-methoxyphenyl)butanamide 108



4-Bromo-*N*-(2-methoxyphenyl)butanamide **106** (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.). **108** 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)

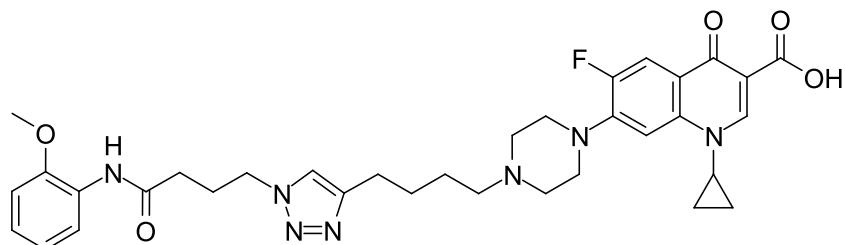
¹H NMR (400 MHz, CDCl₃ d₁) δ / ppm = 8.32 (dd, *J* = 7.9, 1.0 Hz, 1 H, *ortho* to NH), 7.86 (br s, 1 H, NH), 7.00 (td, *J* = 7.5, 1.5 Hz, 1 H, *para* to NH), 6.90 (td, *J* = 7.7, 1.1 Hz, 1 H, *para* to OCH₃), 6.83 (dd, *J* = 8.1, 1.4 Hz, 1 H, *ortho* to OCH₃), 3.81 (s, 3 H, CH₃), 3.33 (t, *J* = 6.7 Hz, 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.¹⁹¹

9.43 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 109



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **66** (24.1 mg, 58.6 μ mol, 1 eq.) and 4-azido-*N*-(2-methoxyphenyl)butanamide **108** (13.7 mg, 58.5 μ mol, 1 eq.) were dissolved in water (3 ml), *t*-BuOH (9 ml) and CH_2Cl_2 (9 ml), and the mixture was degassed by bubbling through N_2 . A solution of CuSO_4 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), CH_2Cl_2 (25 ml) and MeOH (5 ml) were added and the organic layer was separated off, dry-loaded onto SiO_2 and purified by column chromatography using a CombiFlash (SiO_2 , 3-23 % MeOH/ CH_2Cl_2). The combined pure fractions were dried with MgSO_4 and evaporated under reduced pressure. **109** was obtained as a clear amorphous solid (14.7 mg, 22.8 μ mol, 39.0 %).

TLC R_f = 0.28 (10 % MeOH/ CH_2Cl_2)

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)

$^1\text{H NMR}$ (400 MHz, CDCl_3) δ / ppm = 15.05 (br s, 1 H, $\text{C}(=\text{O})\text{OH}$), 8.76 (s, 1 H, *ortho* to $\text{C}(=\text{O})\text{OH}$), 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, $\text{CH}=\text{CCH}_2$), 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 OCH_3), 6.88 (dd, J = 8.1, 1.4 Hz, 1 H, *ortho* to OCH_3), 4.47 (t, J = 6.7 Hz, 2 H, $\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 3.88 (s, 3 H, CH_3), 3.54 (tt, J = 6.9, 4.0 Hz, 1 H, $\text{NCH}(\text{CH}_2)_2$), 3.35 (br t, J = 4.7 Hz, 4 H, $\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)\text{CH}_2\text{CH}_2$), 2.76 (t, J = 7.5 Hz, 2 H, $\text{CH}=\text{CCH}_2$), 2.66 (t, J = 4.7 Hz, 4 H, $\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2)\text{CH}_2$), 2.47 (t, J = 7.3 Hz, 2 H, $\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 2.44 (t, J = 6.8 Hz, 2 H, $\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 2.32 (quin, J = 6.7 Hz, 2 H, $\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 1.75 (quin, J = 7.6 Hz, 2 H, $\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 1.61 (quin, J = 7.5 Hz, 2 H, $\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 1.35 - 1.42 (m, 2 H, $\text{NCH}(\text{CH}_2)_2$), 1.17 - 1.22 (m, 2 H, $\text{NCH}(\text{CH}_2)_2$)

$^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ / ppm = 177.1 ($\text{C}(=\text{O})\text{CC}(=\text{O})\text{OH}$), 169.5 ($\text{NH}\text{C}(=\text{O})$), 167.0 ($\text{C}(=\text{O})\text{OH}$), 153.7 (d, J = 251.4 Hz, *ipso* to F), 148.1 ($\text{CH}=\text{CCH}_2$), 147.8 (*ipso* to OCH_3), 147.3 ($\text{C}=\text{CC}(=\text{O})\text{OH}$), 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 OCH_3), 120.9 ($\text{CH}=\text{CCH}_2$), 119.7 (*para* to piperazine, and *ortho* to NH and *meta* to OCH_3), 112.4 (d, J = 23.4 Hz, *ortho* to C=O and *ortho* to F), 109.9 (*ortho* to OCH_3 and *meta* to NH), 108.1 ($\text{C}(=\text{O})\text{OH}$), 104.7 (*meta* to C=O and *meta* to F), 58.1 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 55.6 (CH_3), 52.8 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)$, 49.8 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)\text{CH}_2\text{CH}_2$), 49.1 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 35.2 ($\text{NCH}(\text{CH}_2)_2$), 33.8 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 27.3 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 26.4 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 26.0 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 25.5 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 8.2 (NCH

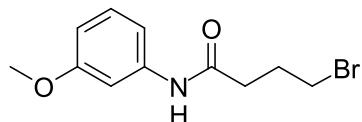
$(\underline{\text{CH}_2})_2$

^{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.

9.44 4-Bromo-*N*-(3-methoxyphenyl)butanamide 111



3-Methoxyaniline **110** (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 **54** (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. **111** 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)

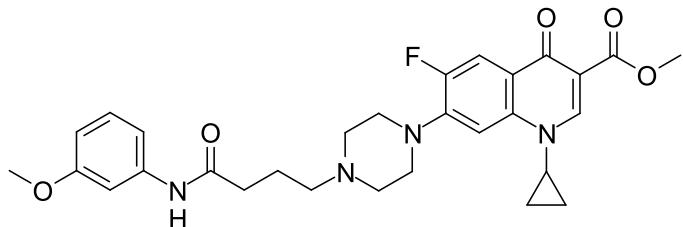
^1H NMR (400 MHz, CDCl_3 d₁) δ / ppm = 8.45 (s, 1 H, NH), 7.27 (t, J = 2.2 Hz, 1 H, *ortho* to OCH_3 and *ortho* to NH), 7.14 (t, J = 8.1 Hz, 1 H, *meta* to OCH_3 and *meta* to NH), 7.02 (d, J = 8.3 Hz, 1 H, *para* to OCH_3), 6.62 (dd, J = 8.2, 2.1 Hz, 1 H, *para* to NH), 3.71 (s, 3 H, CH_3), 3.42 (t, J = 6.5 Hz, 2 H, CH_2Br), 2.51 (t, J = 6.9 Hz, 2 H, C(=O) CH_2), 2.19 (quin, J = 6.8 Hz, 2 H, C(=O) CH_2CH_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.

9.45 Methyl 1-cyclopropyl-6-fluoro-7-(4-((3-methoxyphenyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 112



Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate **98** (500 mg, 1.45 mmol, 1 eq.), 4-bromo-*N*-(3-methoxyphenyl)butanamide **111** (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. **112** 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(CH₂)₂), 1.11 - 1.17 (m, 2 H, NCH(CH₂)₂)

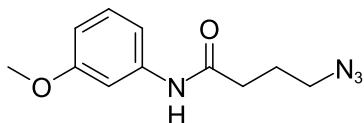
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 173.1 (C(=O)CC(=O)OCH₃), 170.9 (NHC(=O)), 166.3 (C(=O)OCH₃), 160.1 (*ipso* to OCH₃), 153.3 (d, J = 250.1 Hz, *ipso* to F), 148.4 (C=CC(=O)OCH₃), 144.1 (d, J = 10.1 Hz, *ipso* to piperazine), 139.4 (*ipso* to NH), 138.0 (*para* to F), 129.6 (*meta* to NH and *meta* to 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.

9.46 4-Azido-*N*-(3-methoxyphenyl)butanamide 113



4-Bromo-*N*-(3-methoxyphenyl)butanamide **111** (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. **113** 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)

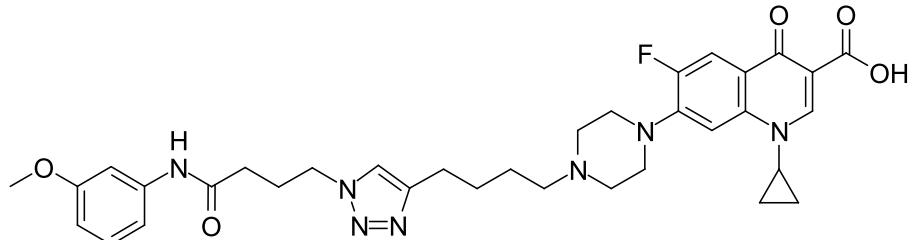
$^1\text{H NMR}$ (400 MHz, MeOD) δ / ppm = 8.63 (br s, 1 H, NH), 7.26 (t, J = 2.3 Hz, 1 H, *ortho* to OCH_3 and *ortho* to NH), 7.15 (t, J = 8.1 Hz, 1 H, *meta* to OCH_3 and *meta* to NH), 7.01 (dd, J = 7.8, 1.6 Hz, 1 H, *para* to OCH_3), 6.63 (dd, J = 8.2, 1.9 Hz, 1 H, *para* to NH), 3.69 (s, 3 H, CH_3), 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.

9.47 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 114



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **66** (24.1 mg, 58.6 μmol , 1 eq.) and 4-azido-*N*-(3-methoxyphenyl)butanamide **113** (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. **114** 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 d_6) δ / ppm = 15.23 (br s, 1 H, $\text{C}(=\text{O})\text{OH}$), 9.89 (s, 1 H, NH), 8.66 (s, 1 H, *ortho* to $\text{C}(=\text{O})\text{OH}$), 7.90 (d, $J = 13.4$ Hz, 1 H, *ortho* to F), 7.88 (s, 1 H, $\text{CH}=\text{CCH}_2$), 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 OCH_3 and *meta* to NH), 7.08 (d, $J = 7.8$ Hz, 1 H, *para* to OCH_3), 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, $\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 3.81 (tt, $J = 6.7, 4.0$ Hz, 1 H, $\text{NCH}(\text{CH}_2)_2$), 3.70 (s, 3 H, CH_3), 3.28 - 3.32 (m, 4 H, $\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)\text{CH}_2\text{CH}_2$), 2.64 (t, $J = 7.5$ Hz, 2 H, $\text{CH}=\text{CCH}_2$), 2.56 (m, $J = 4.2, 4.2$ Hz, 4 H, $\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2)\text{CH}_2$), 2.38 (t, $J = 7.3$ Hz, 2 H, $\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 2.30 (t, $J = 7.4$ Hz, 2 H, $\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 2.10 (quin, $J = 7.1$ Hz, 2 H, $\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 1.64 (quin, $J = 7.5$ Hz, 2 H, $\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 1.51 (quin, $J = 7.2$ Hz, 2 H, $\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 1.27 - 1.33 (m, 2 H, $\text{NCH}(\text{CHH})_2$), 1.15 - 1.20 (m, 2 H, $\text{NCH}(\text{CHH})_2$)

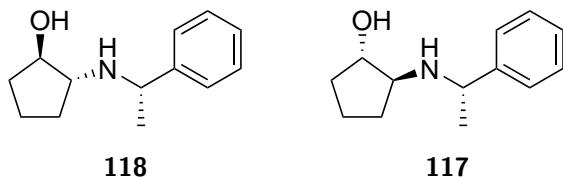
$^{13}\text{C NMR}$ (101 MHz, DMSO d_6) δ / ppm = 176.3 ($\text{C}(=\text{O})\text{CC}(=\text{O})\text{OH}$), 170.1 ($\text{NHC}(=\text{O})$), 165.9 ($\text{C}(=\text{O})\text{OH}$), 159.4 (*ipso* to OCH_3), 153.0 (d, $J = 248.6$ Hz, *ipso* to F), 148.0 ($\text{CH}=\text{CCH}_2$), 146.9 ($\text{C}=\text{CC}(=\text{O})\text{OH}$), 145.2 (d, $J = 10.7$ Hz, *ipso* to piperazine), 140.3 (*para* to F), 139.2 (*ipso* to NH), 129.4 (*meta* to OCH_3 and *meta* to NH), 121.7 ($\text{CH}=\text{CCH}_2$), 118.5 (d, $J = 7.5$ Hz, *para* to piperazine), 111.3 (*para* to OCH_3), 110.9 (d, $J = 22.4$ Hz, *ortho* to C=O and *ortho* to F), 108.4 (*para* to NH), 106.7 ($\text{CC}(=\text{O})\text{OH}$), 106.3 (*meta* to C=O and *meta* to F), 104.8 (*ortho* to OCH_3 and *ortho* to NH), 57.3 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 54.9 (CH_3), 52.4 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2)\text{CH}_2$), 49.5 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)\text{CH}_2\text{CH}_2$), 49.4 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)\text{CH}_2\text{CH}_2$), 48.7 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 35.8 ($\text{NCH}(\text{CH}_2)_2$), 32.9 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 26.8 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 25.7 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 25.5 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 24.9 ($\text{CH}=\text{CCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{N}$), 7.6 ($\text{NCH}(\text{CH}_2)_2$)

$^{19}\text{F NMR}$ (376.45 MHz, DMSO d_6) δ / ppm = -121.5 (s, ciprofloxacin F)

HRMS (ESI $^+$) m/z / Da = 646.3159, $[\text{M}+\text{H}]^+$ found, $[\text{C}_{34}\text{H}_{41}\text{FN}_7\text{O}_5]^+$ requires 646.3153

The compound has not been reported previously.

9.48 $(1S,2S)$ -2-(((*S*)-1-Phenylethyl)amino)cyclopentan-1-ol 117 and $(1R,2R)$ -2-(((*S*)-1-phenylethyl)amino)cyclopentan-1-ol 118



(S)-1-Phenylethan-1-amine **116** (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 **115** (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). **118** was obtained as a pale yellow oil (4.08 g, 19.9 mmol, 32.6 %). **117** 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 117

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 118

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)

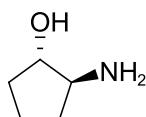
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 144.75 (*ipso* to CHCH₃), 128.26 (*meta* to CHCH₃), 126.72 (*para* to CHCH₃), 126.30 (*ortho* to CHCH₃), 77.65 (CHOH), 63.38 (CHNH), 56.20 (CHCH₃), 31.74 (CH₂CHOH), 29.22 (CH₂CHNH), 24.58 (CH₃), 19.57 (CH₂CH₂CHOH)

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,^{179,180} 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.¹⁸¹

9.49 (1*S*,2*S*)-2-Aminocyclopentan-1-ol 119



(1*S*,2*S*)-2-((*S*)-1-Phenylethyl)amino)cyclopentan-1-ol **117** (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. **119** 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)

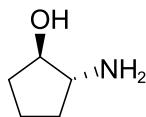
¹³C NMR (101 MHz, MeOD) δ / ppm = 80.6 (CHOH), 60.7 (CHNH₂), 33.2 (CH₂CHOH), 32.2 (CH₂CHNH₂), 21.2 (CH₂CH₂CHOH)

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.^{180,192}

9.50 (1*R*,2*R*)-2-Aminocyclopentan-1-ol **120**



(1*R*,2*R*)-2-(((*S*)-1-Phenylethyl)amino)cyclopentan-1-ol **118** (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. **120** 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)

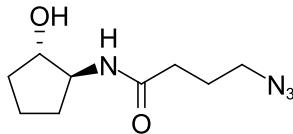
¹³C NMR (101 MHz, MeOD) δ / ppm = 80.7 (CHOH), 60.8 (CH₂NH₂), 33.2 (CH₂CHOH), 32.1 (CH₂CH₂NH₂), 21.2 (CH₂CH₂CHOH)

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.^{180,192}

9.51 4-Azido-*N*-((1*S*,2*S*)-2-hydroxycyclopentyl)butanamide **123**



4-Chloro-*N*-((1*S*,2*S*)-2-hydroxycyclopentyl)butanamide **144** (35.0 mg, 0.170 mmol, 1 eq.) and NaN₃ (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. **123** 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)

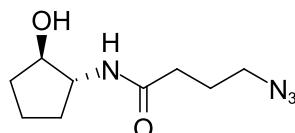
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 173.8 (C=O), 79.7 (CHOH), 61.0 (CHNH), 50.7 (CH₂N₃), 32.8 (CH₂C=O), 32.6 (CH₂CHOH), 30.5 (CH₂CHNH), 24.7 (CH₂CH₂N₃), 21.3 (CH₂CH₂CHOH)

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.

9.52 4-Azido-*N*-((1*R*,2*R*)-2-hydroxycyclopentyl)butanamide 124



4-Chloro-*N*-((1*R*,2*R*)-2-hydroxycyclopentyl)butanamide **145** (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. **124** 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)

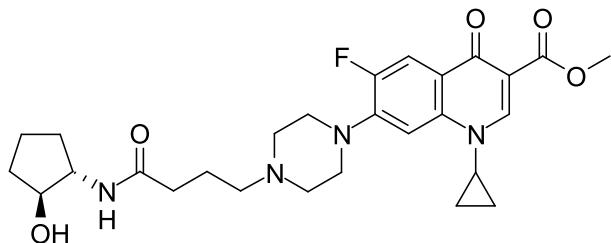
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 173.8 (C=O), 78.8 (CHOH), 59.9 (CHNH), 50.5 (CH₂N₃), 32.5 (CH₂C=O), 32.0 (CH₂CHOH), 29.5 (CH₂CHNH), 24.6 (CH₂CH₂N₃), 20.7 (CH₂CH₂CHOH)

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.

9.53 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 125



4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid trifluoroacetate **142** (52.1 mg, 95.5 μ mol, 1 eq.), (1*S*,2*S*)-2-aminocyclopentan-1-ol **119** (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. **125** 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)

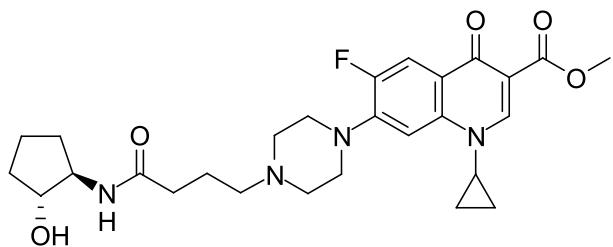
^{19}F NMR (376.45 MHz, MeOD) δ / ppm = -125.5

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.

9.54 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 126



4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid trifluoroacetate **142** (200 mg, 0.367 mmol, 1 eq.), (1*R*,2*R*)-2-aminocyclopentan-1-ol **120** (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 \times 10 ml). The combined organic fractions were dried with MgSO₄ and evaporated under reduced pressure. **126** 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)

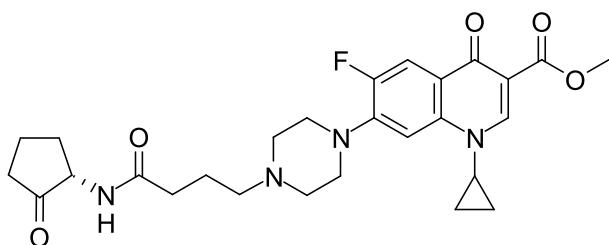
¹⁹F NMR (376.45 MHz, DMSO d₆) δ / ppm = -124.3 (ciprofloxacin F)

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.

9.55 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 127



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 **125** (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. **127** 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

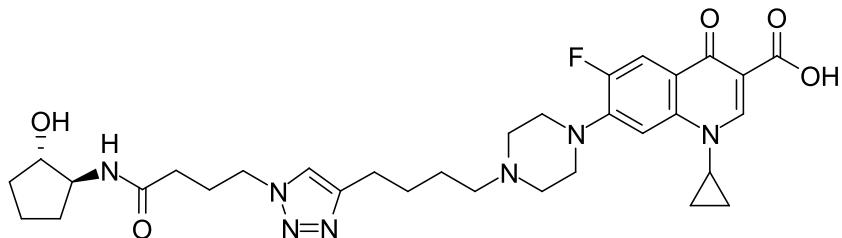
HRMS (ESI⁺) *m/z* / Da = 513.2495, [M+H]⁺ found, [C₂₇H₃₄FN₄O₅]⁺ requires 513.2513

remove
unless
very
active
as not
fully
characterised

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

The compound has not been reported previously.

9.56 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 128



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **66** (82.0 mg, 199 μmol , 4 eq.) and 4-azido-*N*-((1*S*,2*S*)-2-hydroxycyclopentyl)butanamide **123** (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. **128** 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), 52.3 (br s, CH=CCH₂CH₂CH₂N(CH₂)CH₂), 49.3 (br s, CH=CCH₂CH₂CH₂N(CH₂CH₂)CH₂), 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)

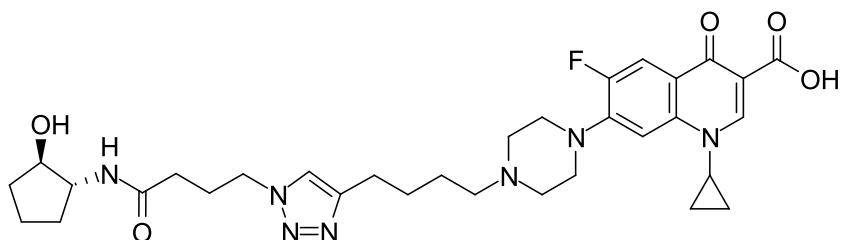
¹⁹F NMR (376.45 MHz, MeOD) δ / ppm = -121.5

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.

9.57 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 129



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **66** (42.9 mg, 104 μ mol, 1 eq.) and 4-azido-*N*-((1*R*,2*R*)-2-hydroxycyclopentyl)butanamide **124** (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. **129** 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)

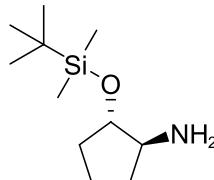
¹⁹F NMR (376.45 MHz, MeOD) δ / ppm = -122.1 (s, ciprofloxacin F)

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.

9.58 (1*S*,2*S*)-2-((*tert*-Butyldimethylsilyl)oxy)cyclopentan-1-amine 130



(1*S*,2*S*)-2-Aminocyclopentan-1-ol **119** (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). **130** 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)

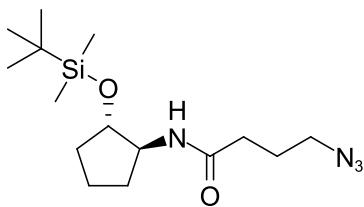
¹H NMR (400 MHz, CDCl₃) δ / ppm = 4.13 (q, *J* = 5.8 Hz, 1 H, CHOSi), 3.31 (td, *J* = 7.1, 5.2 Hz, 1 H, CHNH₂), 2.09 - 2.19 (m, 1 H, CHHCHNH₂), 1.97 (ddq, *J* = 8.8, 7.0, 6.0 Hz, 1 H, CHHCHOSi), 1.74 - 1.86 (m, 2 H, CH₂CH₂CHOSi), 1.64 - 1.74 (m, 1 H, CHHCHOSi), 1.58 (ddt, *J* = 13.2, 9.1, 6.0 Hz, 1 H,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

9.59 4-Azido-*N*-(*(1S,2S)*-2-((*tert*-butyldimethylsilyl)oxy)cyclopentyl)butanamide 134



(*1S,2S*)-2-((*tert*-Butyldimethylsilyl)oxy)cyclopentan-1-amine **130** (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. **134** 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) δ / 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)

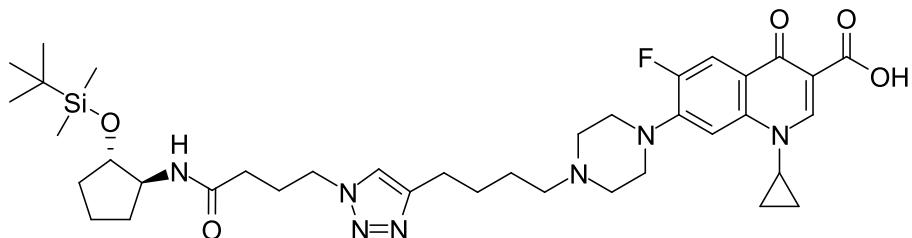
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 171.17 (C=O), 77.80 (CHOSi), 58.36 (CHNH), 50.77 (CH₂N₃), 33.29 (CH₂C=O), 32.57 (CH₂CHOSi), 29.36 (CH₂CHNH), 25.72 (C(CH₃)₃), 24.77 (CH₂CH₂N₃), 20.40 (CH₂CH₂CHO Si), 17.95 (C(CH₃)₃), -4.75 (SiCH₃)

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.

9.60 7-(4-(1-(4-((1*S*,2*S*)-2-((*tert*-butyldimethylsilyl)oxy)cyclopentyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-ylbutyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-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 **66** (42.9 mg, 104 μ mol, 1 eq.) and 4-azido-*N*-((1*S*,2*S*)-2-((*tert*-butyldimethylsilyl)oxy)cyclopentyl)butanamide **134** (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. **138** 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)

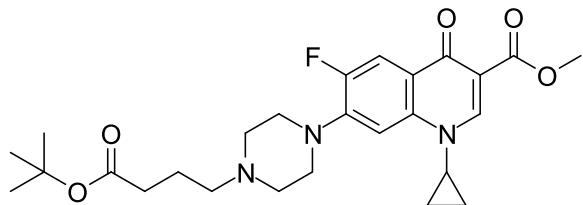
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 176.9 (C(=O)CC(=O)OH), 170.9 (CH₂C(=O)NH), 166.9 (C(=O)OH), 153.5 (d, *J* = 251.4 Hz, *ipso* to F), 147.9 (CH=CCH₂), 147.2 (C=CC(=O)OH), 145.8 (d, *J* = 10.4 Hz, *ipso* to piperazine), 139.0 (*para* to F), 120.9 (NCH=CCH₂), 119.4 (d, *J* = 7.8 Hz, *para* to piperazine), 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.

9.61 Methyl 7-(4-(*tert*-butoxy)-4-oxobutyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylate 141



Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate **98** (200 mg, 0.579 mmol, 1 eq.), *tert*-butyl 4-bromobutanoate **140** (103 μl , 130 mg, 0.581 mmol, 1 eq.), NaI (86.9 mg, 0.580 mmol, 1 eq.), TEA (316 μl , 229 mg, 2.27 mmol, 4 eq.) and acetonitrile (10 ml) were stirred in a microwave reactor at 100 $^\circ\text{C}$ for 8 h. A second portion of *tert*-butyl 4-bromobutanoate **157** (103 μl , 130 mg, 0.581 mmol, 1 eq.) was added, and the mixture was stirred in the microwave reactor at 100 $^\circ\text{C}$ for a further 8 h. The mixture was then dry-loaded onto SiO_2 and purified by column chromatography (SiO_2 , 0-4 % MeOH/CH₂Cl₂). **141** was obtained as a white amorphous solid (141 mg, 0.289 mmol, 49.9 %).

TLC $R_f = 0.12$ (4 % MeOH/CH₂Cl₂)

IR (neat) $\nu_{max} / \text{cm}^{-1} = 2961.6$ (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) $\delta / \text{ppm} = 8.39$ (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)

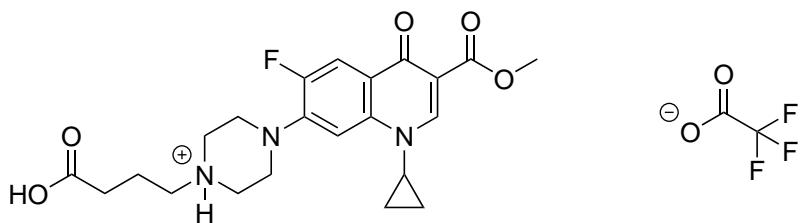
¹³C NMR (101 MHz, CDCl₃) $\delta / \text{ppm} = 172.7$ (C(=O)CC(=O)OCH₃), 172.6 (C(=O)OC(CH₃)₃), 165.9 (C(=O)OCH₃), 153.1 (d, $J = 249.7$ Hz, *ipso* to F), 148.1 (C=CC(=O)OCH₃), 144.3 (d, $J = 10.4$ Hz, *ipso* to piperazine), 137.7 (*para* to F), 122.5 (d, $J = 6.9$ Hz, *para* to piperazine) 112.6 (d, $J = 22.5$ 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) $\delta / \text{ppm} = -123.5$ (s, ciprofloxacin F)

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

The compound has not been reported previously.

9.62 4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid trifluoroacetate 142



Methyl 7-(4-(4-(*tert*-butoxy)-4-oxobutyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylate **141** (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. **142** 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 d₆) 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, $\text{NCH}(\text{CH}_2)_2$)

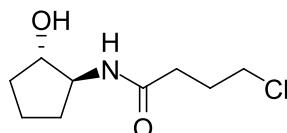
$^{13}\text{C NMR}$ (101 MHz, DMSO d₆) δ / ppm = 173.5 ($\text{CH}_2\text{C}(=\text{O})\text{OH}$), 171.6 ($\text{C}(=\text{O})\text{CC}(=\text{O})\text{OCH}_3$), 164.9 ($\text{C}(=\text{O})\text{OCH}_3$), 158.2 (q, J = 31.5 Hz, $\text{CF}_3\text{C}(=\text{O})\text{OH}$), 152.5 (d, J = 247.6 Hz, *ipso* 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 ($\text{CC}(=\text{O})\text{OCH}_3$), 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 ($\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{CH}_2\text{N}(\text{CH}_2\text{CH}_2)\text{CH}_2\text{CH}_2$), 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 d₆) 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.

9.63 4-Chloro-*N*-(*(1S,2S*)-2-hydroxycyclopentyl)butanamide 144



(1*S*,2*S*)-2-Aminocyclopentan-1-ol **119** (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 **143** (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. **144** 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)

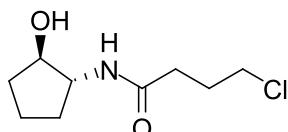
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 173.8 (C=O), 79.4 (CHOH), 60.6 (CHNH), 44.4 (CH₂Cl), 32.8 (CH₂C=O), 32.4 (CH₂CHOH), 30.2 (CH₂CHNH), 28.0 (CH₂CH₂Cl), 21.2 (CH₂CH₂CHOH)

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.

9.64 4-Chloro-*N*-(*1R,2R*)-2-hydroxycyclopentylbutanamide **145**



(*1R,2R*)-2-Aminocyclopentan-1-ol **120** (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 **143** (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. **145** 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, CHHCH₂CHOH), 1.58 - 1.73 (m, 2 H, CHHCH₂CHOH and CHHCHOH), 1.43 (dq, *J* = 12.7, 8.3 Hz, 1 H, CHHCHNH)

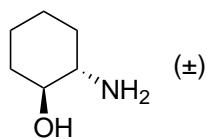
¹³C NMR (101 MHz, CDCl₃) δ / ppm = 173.8 (C=O), 79.4 (CHOH), 60.6 (CHNH), 44.4 (CH₂Cl), 32.8 (CH₂C=O), 32.4 (CH₂CHOH), 30.1 (CH₂CHNH), 28.0 (CH₂CH₂Cl), 21.1 (CH₂CH₂CHOH)

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

$[\alpha]_D^{20}$ / °10⁻¹cm²g⁻¹ = -13.0 (c / g(100 ml)⁻¹ = 0.5, MeOH)

The compound has not been reported previously.

9.65 (*trans*)-2-Aminocyclohexan-1-ol 147



Cyclohexene oxide **146** (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. **147** 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)

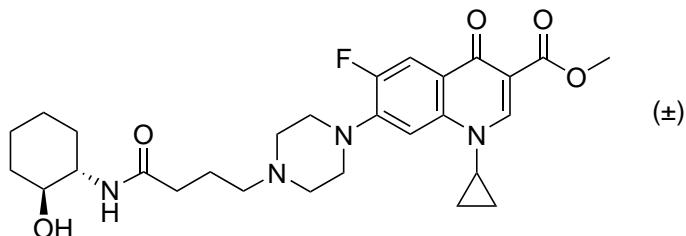
¹H NMR (400 MHz, CDCl₃) δ / ppm = 3.01 (td, *J* = 9.4, 4.8 Hz, 1 H, CHOH), 2.80 - 2.92 (m, 2 H, OH and NH₂), 2.35 (ddd, *J* = 11.1, 9.1, 4.1 Hz, 1 H, CHNH₂), 1.77 - 1.84 (m, 1 H, CHHCHOH), 1.69 - 1.76 (m, 1 H, CHHCHNH₂), 1.56 - 1.66 (m, 1 H, CHHCH₂CHOH), 1.45 - 1.56 (m, 1 H, CHHCH₂CHNH₂), 1.07 - 1.19 (m, 3 H, CHHCH₂CHOH, CHHCH₂CHNH₂ and CHHCHOH), 0.94 - 1.05 (m, 1 H, CHHCHNH₂)

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.¹⁸⁸

9.66 Methyl 1-cyclopropyl-6-fluoro-7-(4-((*trans*)-2-hydroxycyclohexyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 148



4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid trifluoroacetate **142** (200 mg, 0.367 mmol, 1 eq.), (*trans*)-2-aminocyclohexan-1-ol **147** (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. **148** 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)

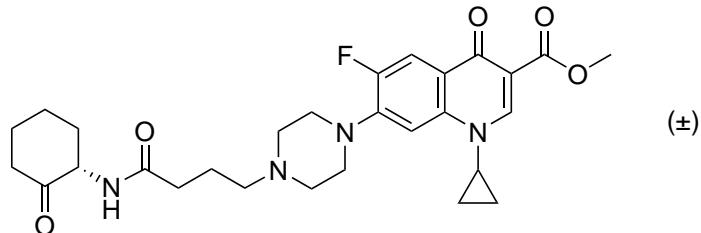
^{13}C NMR (101 MHz, MeOD) δ / ppm = 175.8 (CH₂C(=O)NH), 175.3 (C(=O)CC(=O)OCH₃), 166.8 (C(=O)OCH₃), 154.9 (d, J = 248.8 Hz, *ipso* to F), 150.2 (C=CC(=O)OCH₃), 146.1 (d, J = 10.8 Hz, *ipso* to piperazine), 139.9 (*para* to F), 123.5 (d, J = 7.5 Hz, *para* to piperazine), 113.2 (d, J = 23.2 Hz, *ortho* 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.

9.67 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxocyclohexyl)amino)-butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 149



Methyl 1-cyclopropyl-6-fluoro-7-(4-((*trans*)-2-hydroxycyclohexyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate **148** (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. **149** 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, CH₂CH₂CH₂N), 2.00 (ddquin, J = 13.2, 6.0, 2.9 Hz, 1 H, CH₂CH₂C(=O)), 1.65 - 1.83 (m, 4 H, CH₂CH₂CH₂N), 1.41 - 1.56 (m, 2 H, CH₂CH₂CH₂N and CH₂CH₂C(=O)), 1.20 - 1.30 (m, 2 H, NCH(CH₂)₂), 1.05 - 1.13 (m, 2 H, NCH(CH₂)₂)

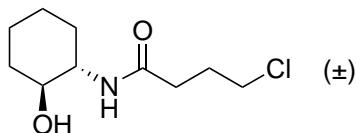
$^{13}\text{C NMR}$ (101 MHz, DMSO d₆) δ / ppm = 207.5 (C(=O)CHNH), 171.7 (C(=O)CC(=O)OCH₃), 171.6 (CH₂C(=O)NH), 165.0 (C(=O)OCH₃), 152.6 (d, J = 247.6 Hz, *ipso* to F), 148.3 (C=CC(=O)OCH₃), 143.9 (br s, *ipso* to piperazine), 138.1 (para to F), 121.8 (d, J = 6.4 Hz, para to piperazine), 111.5 (d, J = 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 (CH₂CH₂CH₂N), 32.9 (C(=O)CH₂CH₂CH₂N), 27.2 (CH₂CH₂C(=O)CHNH), 23.8 (CH₂CH₂CH₂N), 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.

9.68 4-Chloro-*N*-((*trans*)-2-hydroxycyclohexyl)butanamide 150



(*trans*)-2-Aminocyclohexan-1-ol **147** (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 **143** (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. **150** 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)

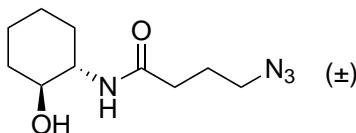
¹H NMR (400 MHz, MeOD) δ / ppm = 3.60 (t, J = 6.6 Hz, 2 H, CH_2Cl), 3.51 - 3.60 (m, 1 H, CH_2NH), 3.28 - 3.39 (m, 1 H, CHOH), 2.37 (td, J = 7.4, 2.3 Hz, 2 H, C(=O)CH₂), 2.06 (quin, J = 7.0 Hz, 2 H, C(=O)CH₂CH₂), 1.97 - 2.01 (m, 1 H, CH_2CHOH), 1.85 - 1.93 (m, 1 H, CH_2CHNH), 1.70 - 1.77 (m, 1 H, $\text{CH}_2\text{CH}_2\text{CHOH}$),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

9.69 4-Azido-*N*-((*trans*)-2-hydroxycyclohexyl)butanamide 151



4-Chloro-*N*-((*trans*)-2-hydroxycyclohexyl)butanamide **150** (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. **151** 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)

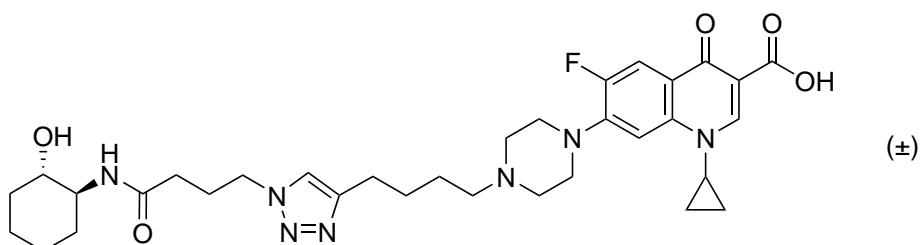
¹H NMR (400 MHz, MeOD) $\delta / \text{ppm} = 7.87$ (d, $J = 7.9$ Hz, 1 H, NH), 5.27 (d, $J = 4.3$ Hz, 1 H, OH), 3.56 (td, $J = 10.5, 4.4$ Hz, 1 H, CHNH), 3.28 - 3.41 (m, 3 H, CHO and CH₂N₃), 2.30 (td, $J = 7.4, 2.7$ Hz, 2 H, C(=O)CH₂), 1.95 - 2.03 (m, 1 H, CHHCHOH), 1.87 (m, 3 H, C(=O)CH₂CH₂ and CHHCHNH),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

9.70 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 152



1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid **66** (40 mg, 97.2 μmol , 1 eq.) and 4-azido-*N*-((*trans*)-2-hydroxycyclohexyl)butanamide **151** (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. **152** 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)

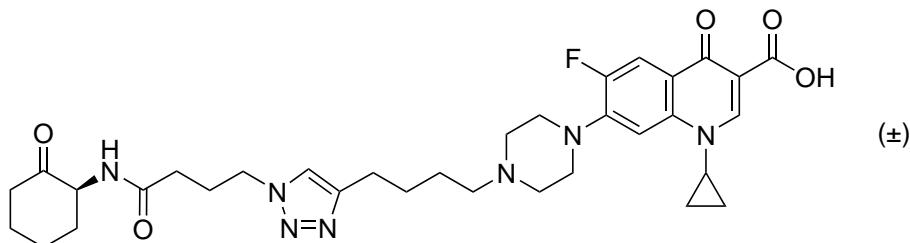
¹³C NMR (101 MHz, DMSO d₆) δ / ppm = 176.4 (C(=O)CC(=O)OH), 170.9 (CH₂C(=O)NH), 166.0 (C(=O)OH), 153.1 (d, J = 252.1 Hz, *ipso* to F), 148.0 (C=CC(=O)OH), 146.9 (CH=CCH₂), 145.3 (d, J = 10.0 Hz, *ipso* to piperazine), 139.2 (para to F), 121.8 (NCH=CCH₂), 118.5 (d, J = 8.3 Hz, *para* to piperazine), 110.9 (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)CH₂CH₂CH₂NCH=C), 31.1 (CH₂CH₂NH), 26.9 (CH=CCH₂CH₂CH₂N), 26.1 (C(=O)CH₂CH₂CH₂NCH=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.

9.71 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 153



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 **152** (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. **153** 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)CH₂CH₂CH₂NH), 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=CCH₂CH₂CH₂NH), 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(CH₂)₂), 1.13 - 1.20 (m, 2 H, NCH(CH₂)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=CCH₂CH₂CH₂NH), 57.0 (CHNH), 52.4 (CH₂CH₂CH₂N(CH₂)CH₂), 49.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂), 49.5 (CH₂CH₂CH₂N(CH₂CH₂)CH₂), 48.7 (C(=O)CH₂CH₂NCH=C), 40.5 (CH₂C(=O)), 35.8 (NCH(CH₂)₂), 33.7 (CH₂CHNH), 31.8 (C(=O)CH₂CH₂NCH=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)

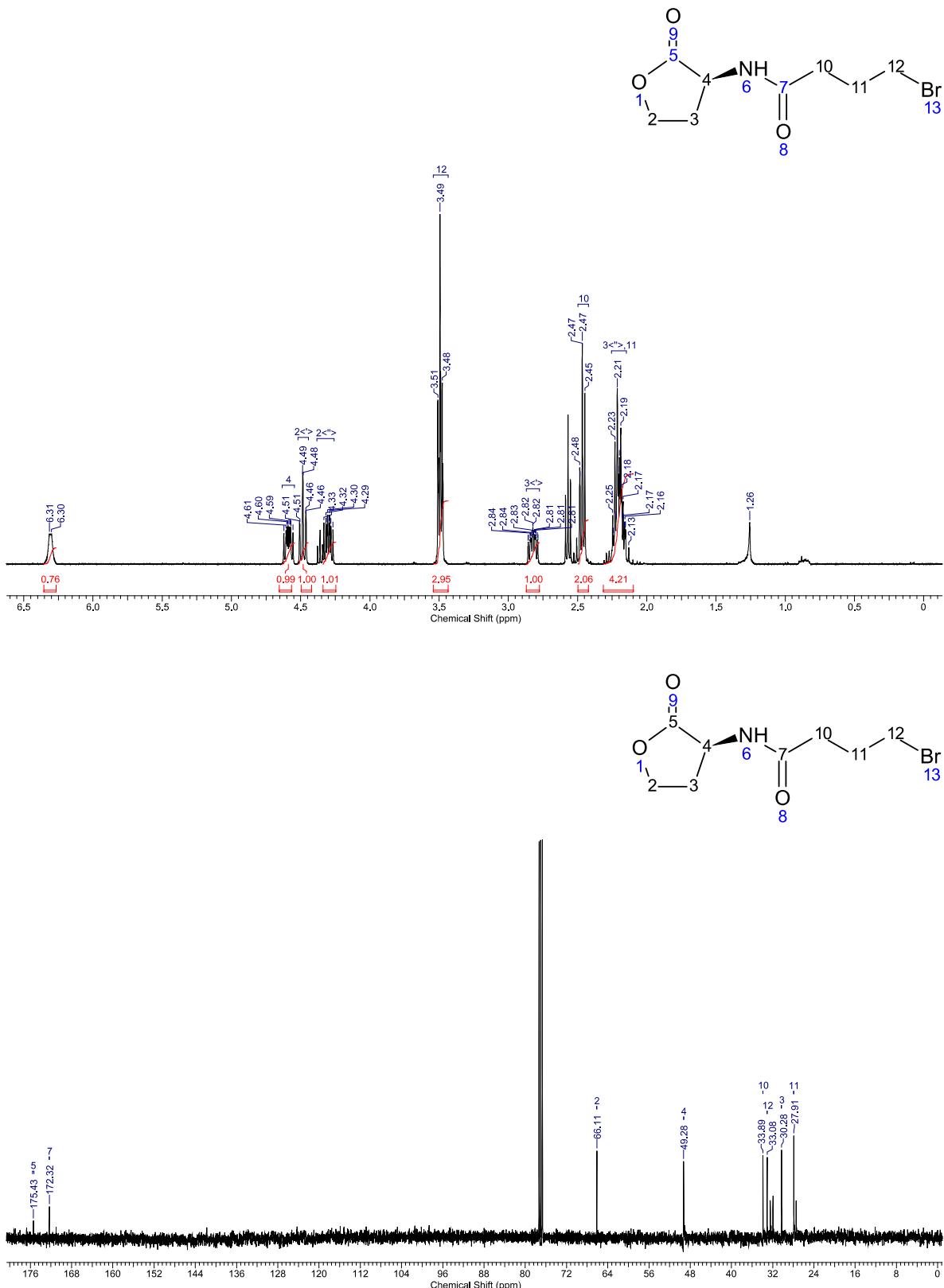
¹⁹F NMR (376 MHz, DMSO d₆) δ / ppm = -121.7 (s, ciprofloxacin F)

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

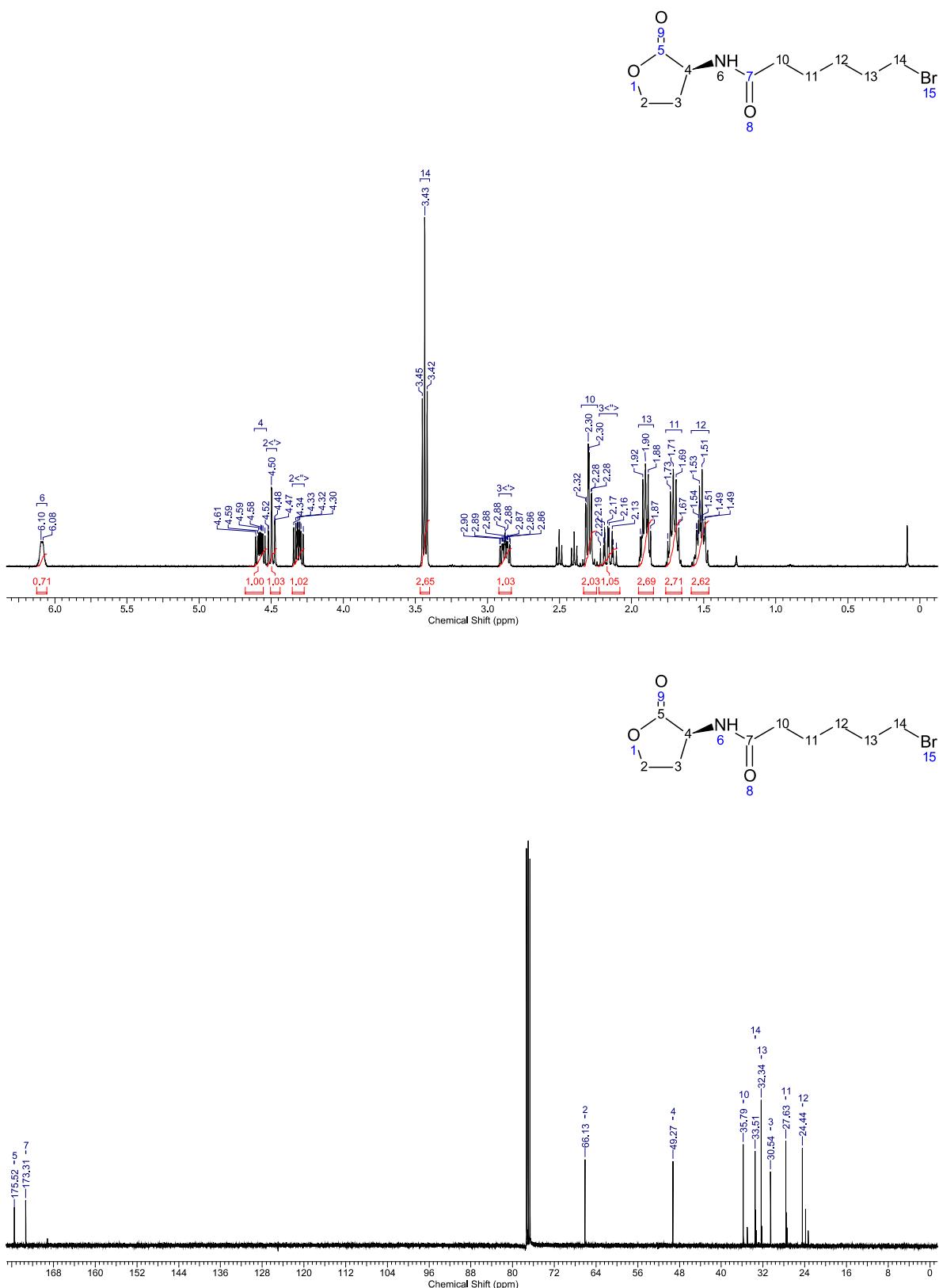
The compound has not been reported previously.

10 NMR spectra

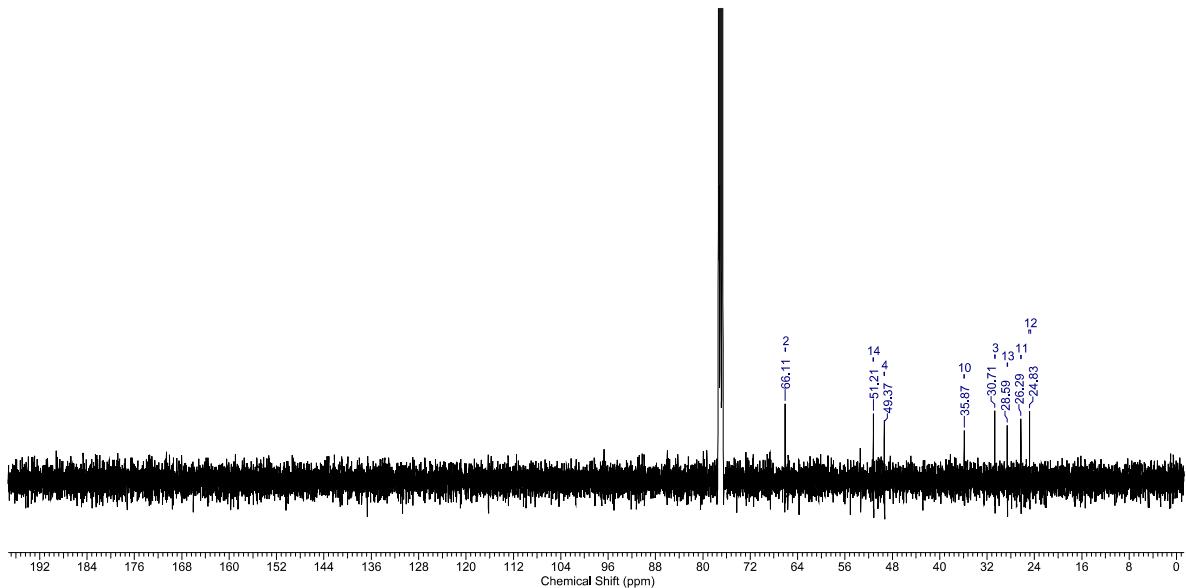
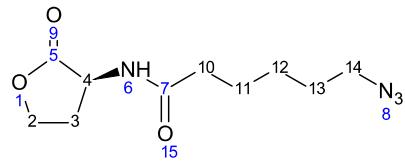
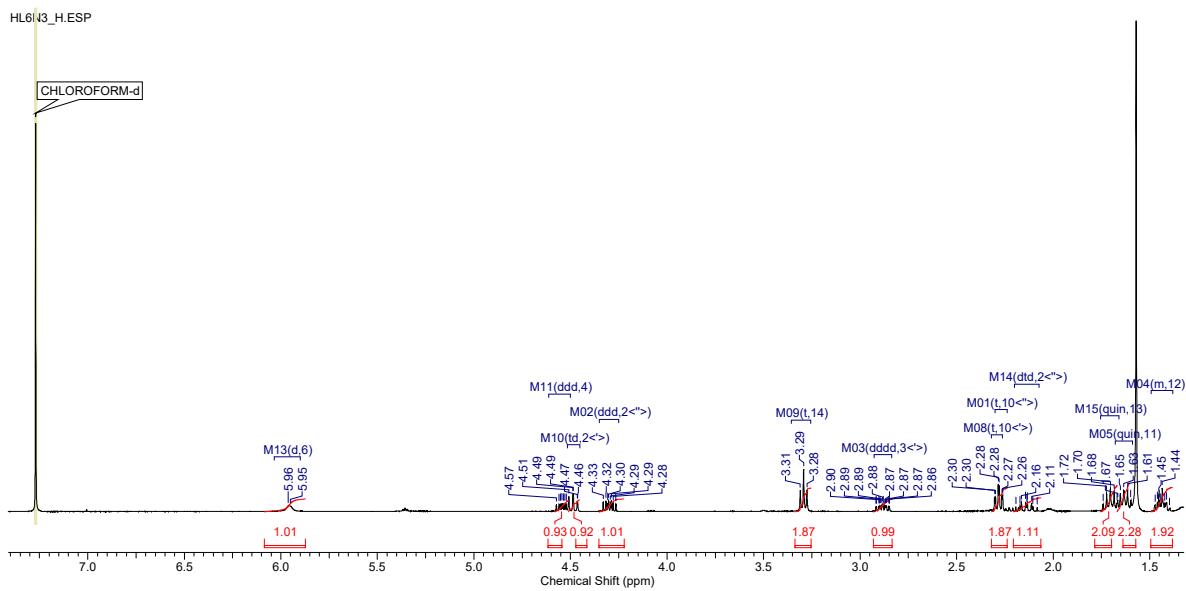
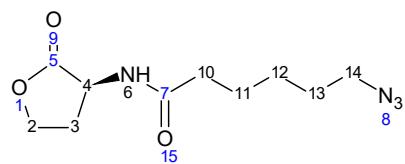
10.1 (*S*)-4-Bromo-*N*-(2-oxotetrahydrofuran-3-yl)butanamide 55



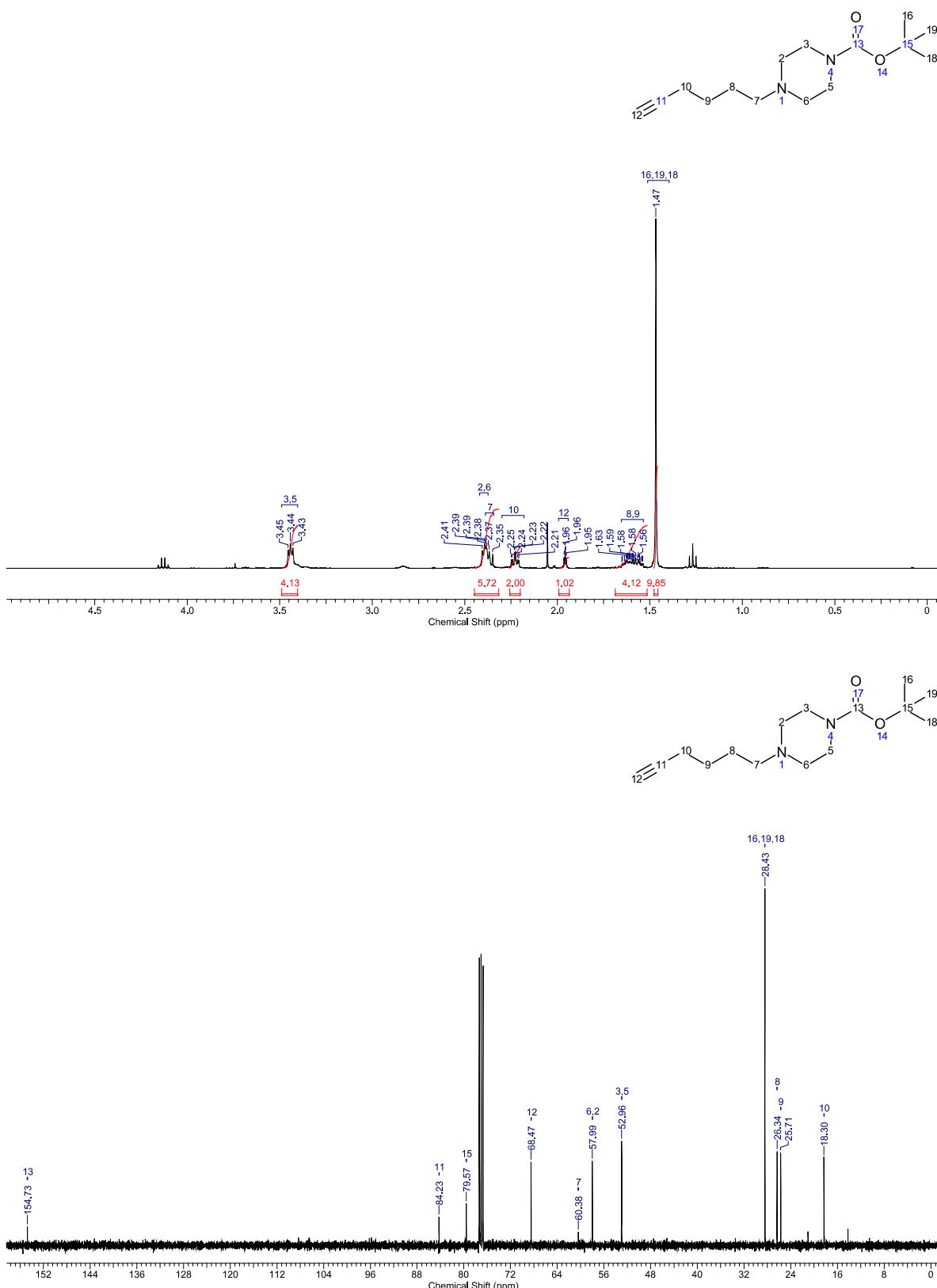
10.2 (*S*)-6-Bromo-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide 58



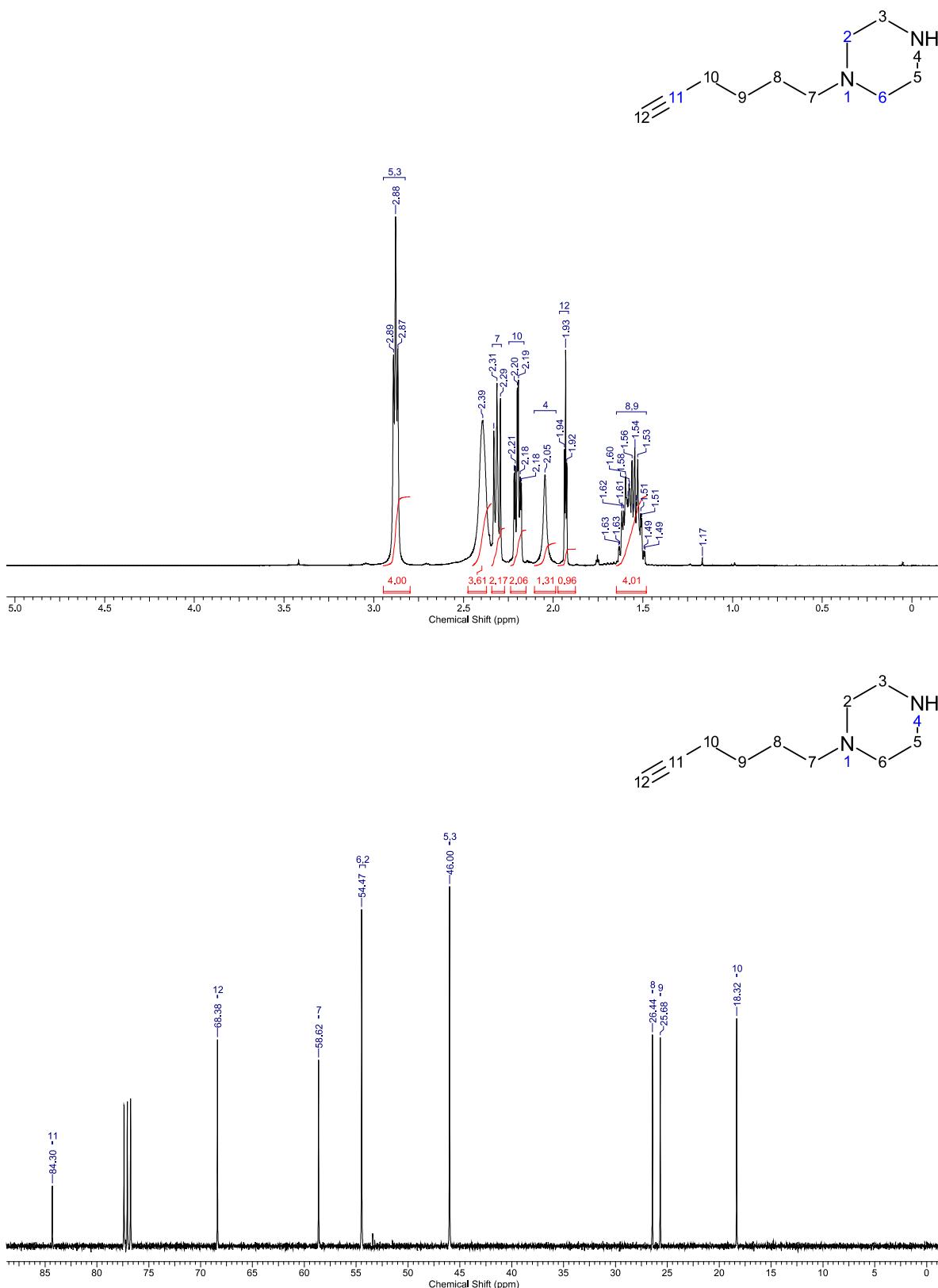
10.3 (S)-6-Azido-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide 59



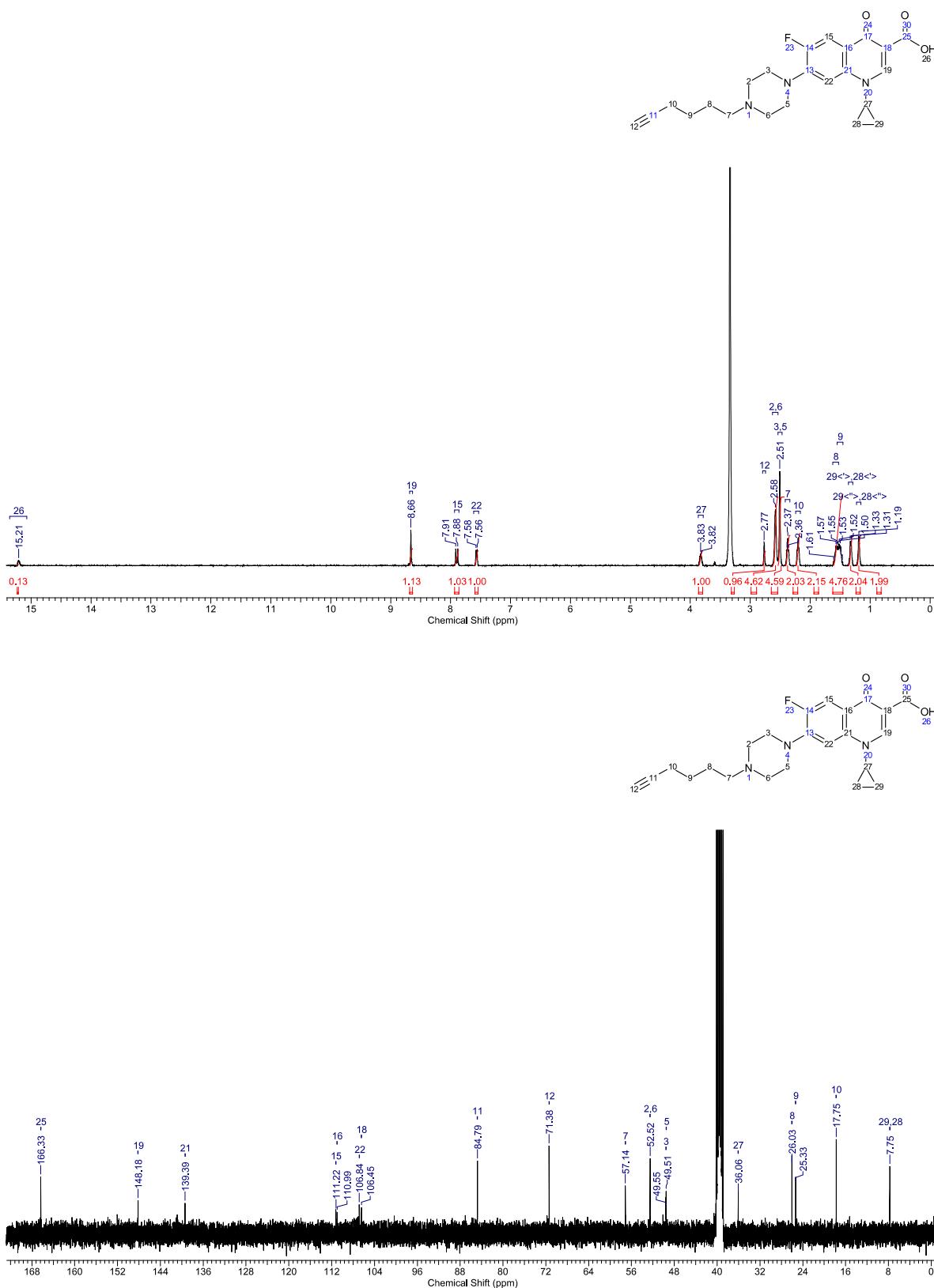
10.4 *tert*-Butyl 4-(hex-5-yn-1-yl)piperazine-1-carboxylate 63



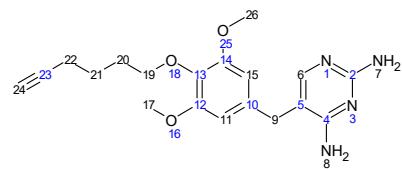
10.5 1-(Hex-5-yn-1-yl)piperazine 64



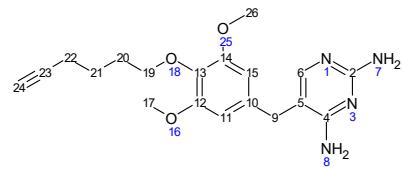
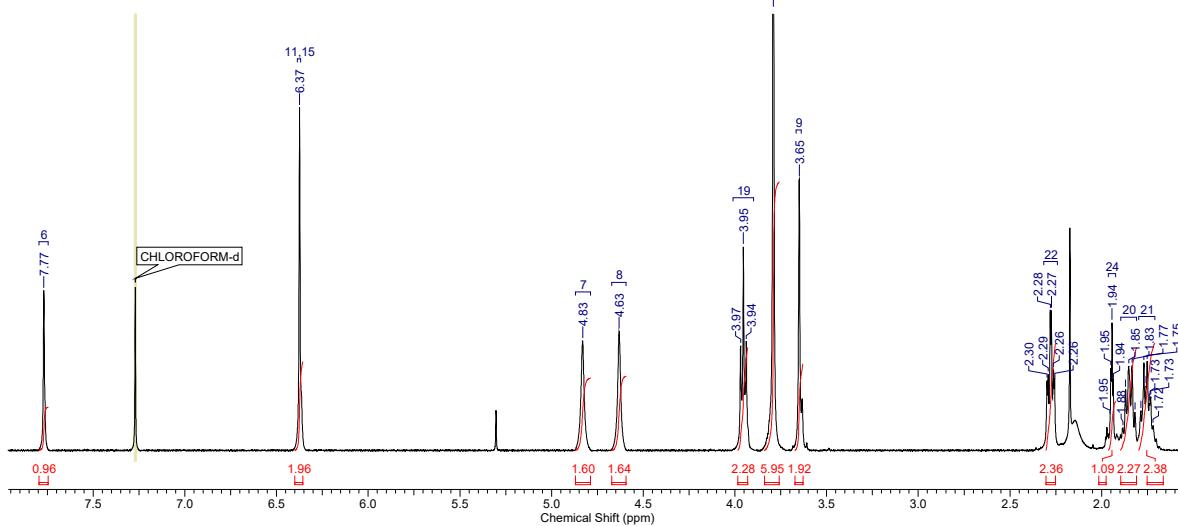
10.6 1-Cyclopropyl-6-fluoro-7-(4-(hex-5-yn-1-yl)piperazin-1-yl)-4-oxo-1,4-dihydro-quinoline-3-carboxylic acid 66



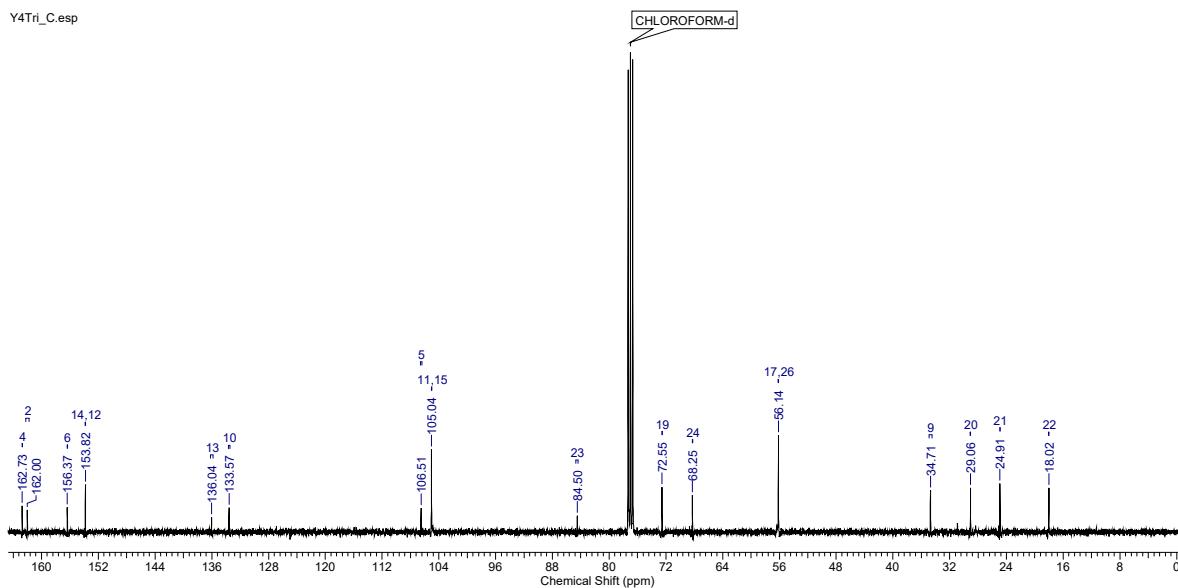
10.7 5-(4-(Hex-5-yn-1-yloxy)-3,5-dimethoxybenzyl)pyrimidine-2,4-diamine 69



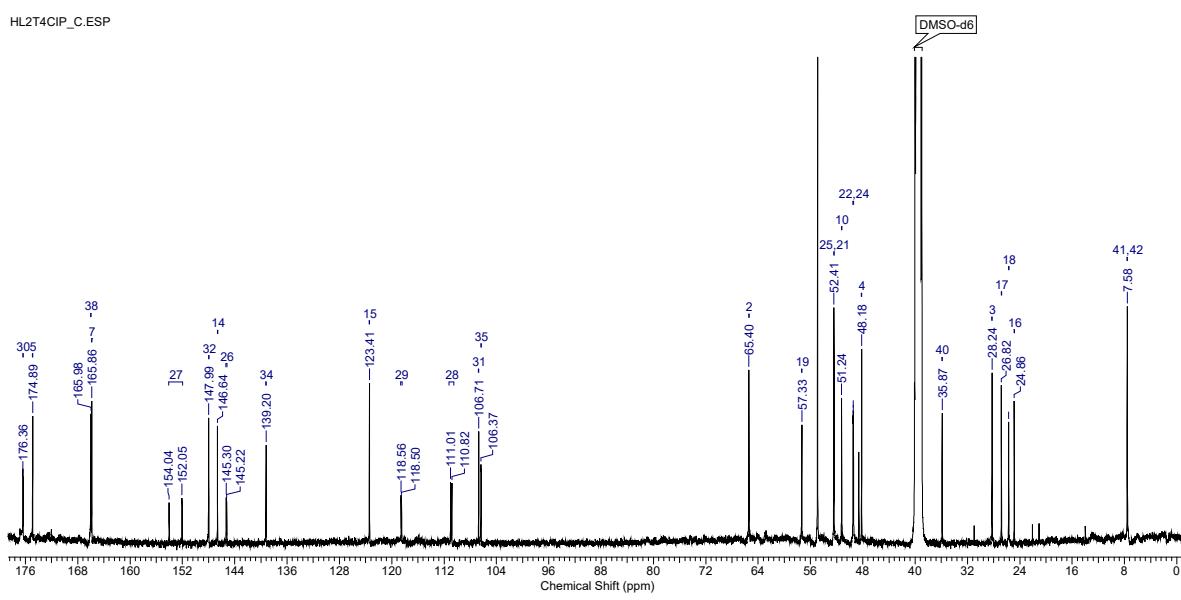
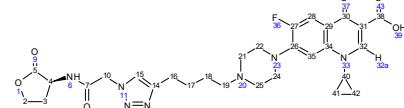
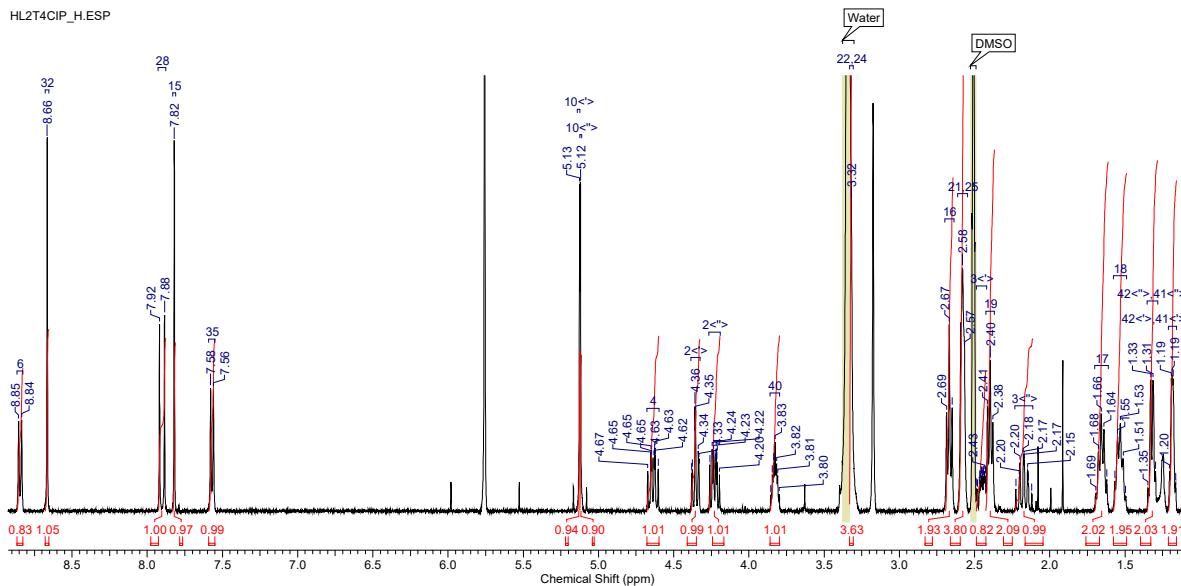
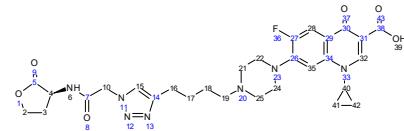
Y4Tri_H.esp



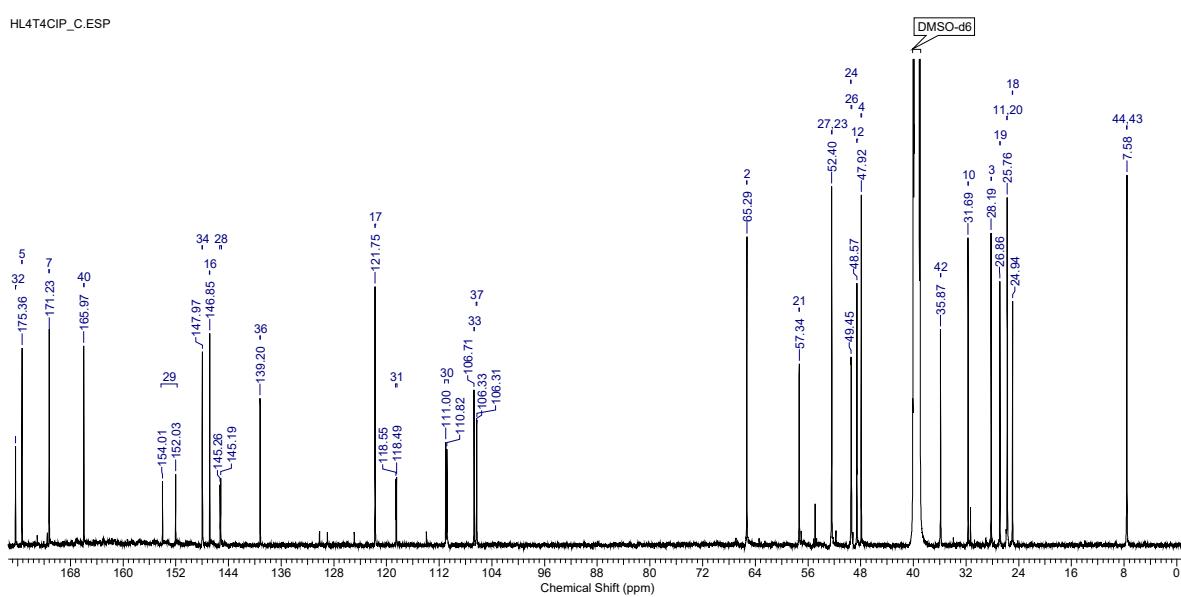
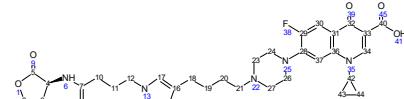
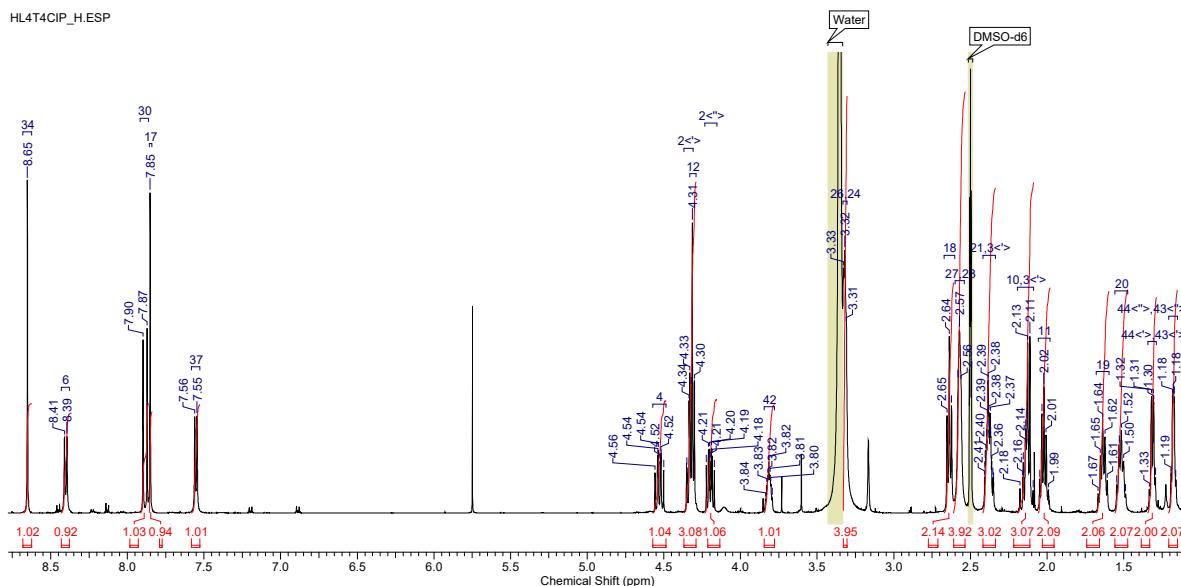
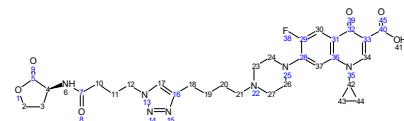
Y4Tri_C.esp



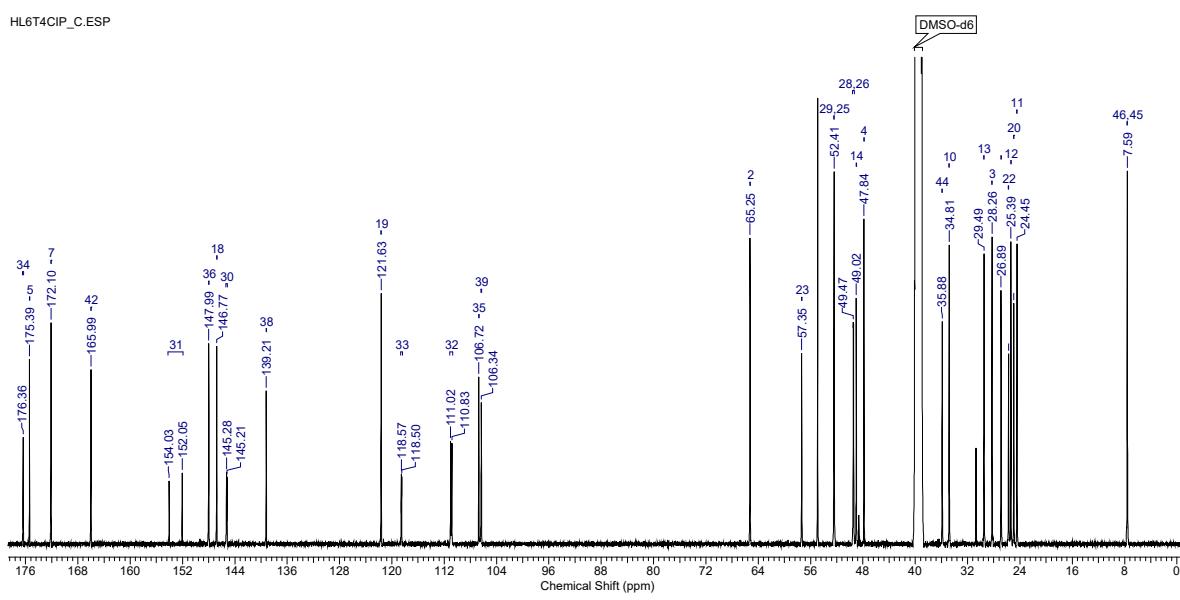
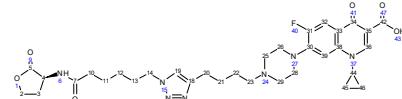
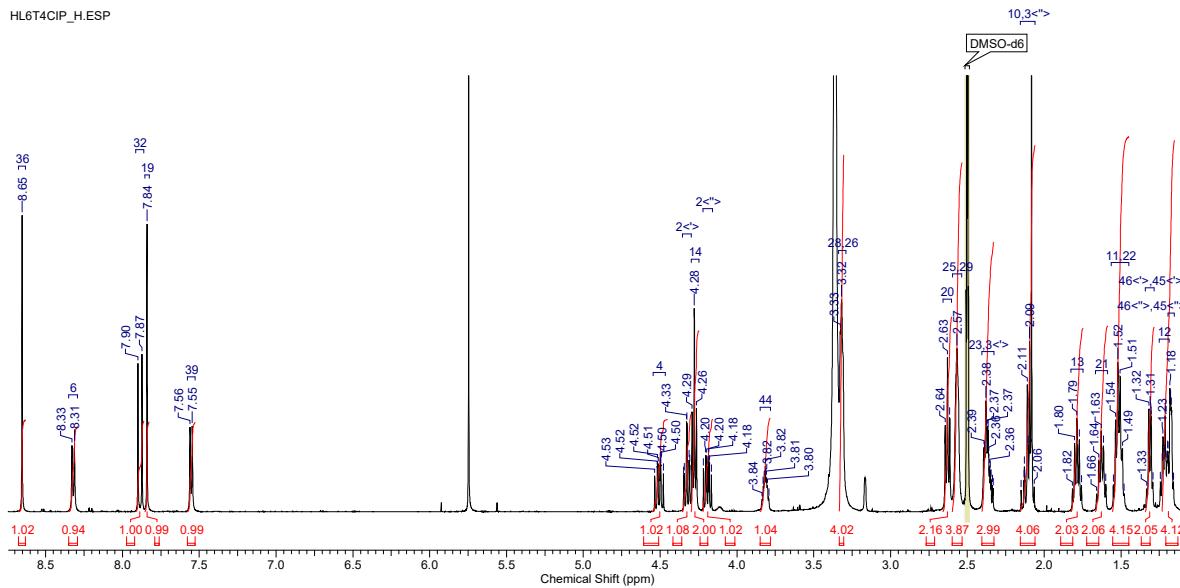
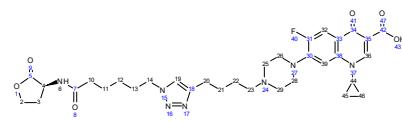
10.8 (*S*)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(2-oxo-2-((2-oxotetrahydrofuran-3-yl)amino)ethyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 70



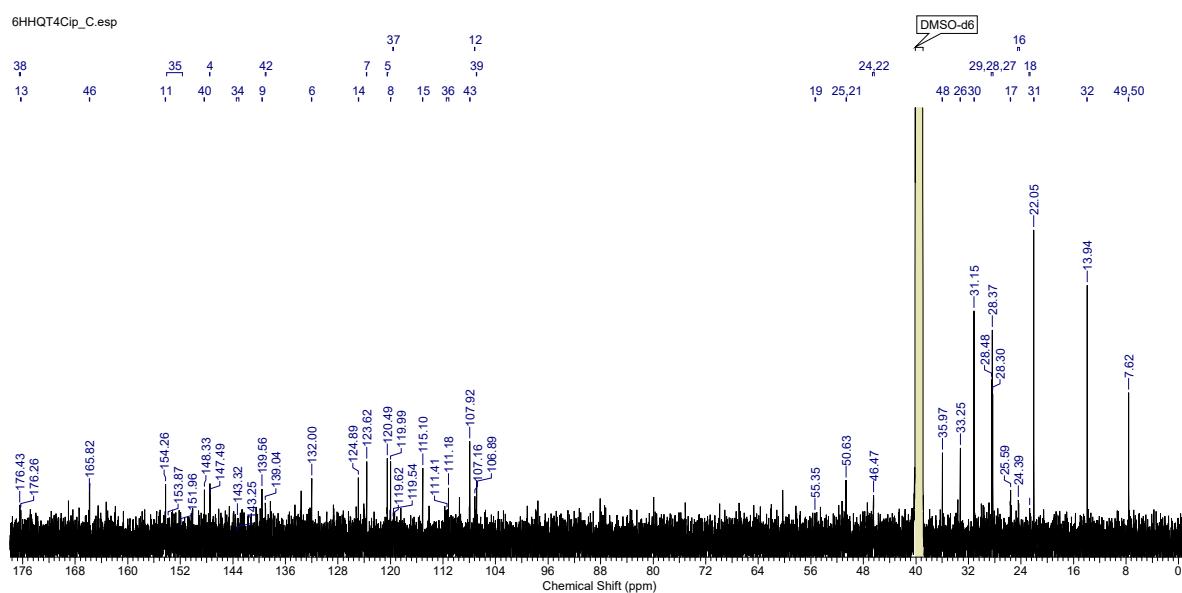
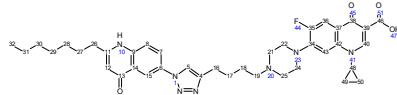
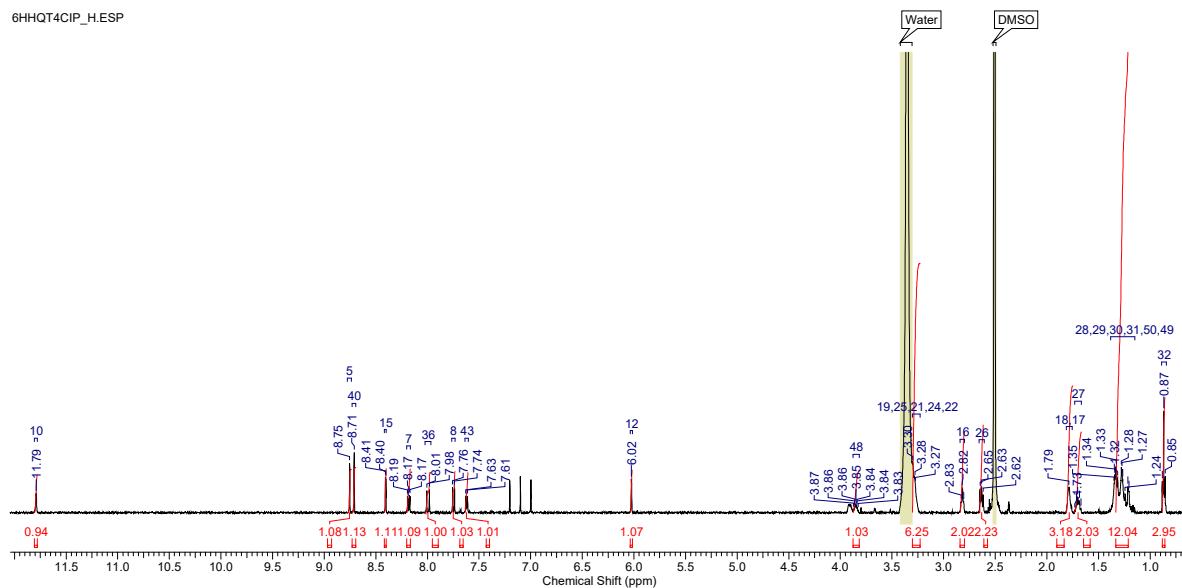
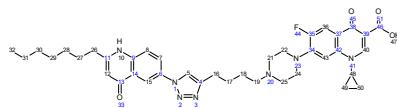
10.9 (*S*)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(4-oxo-4-((2-oxotetrahydrofuran-3-yl)amino)butyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 75



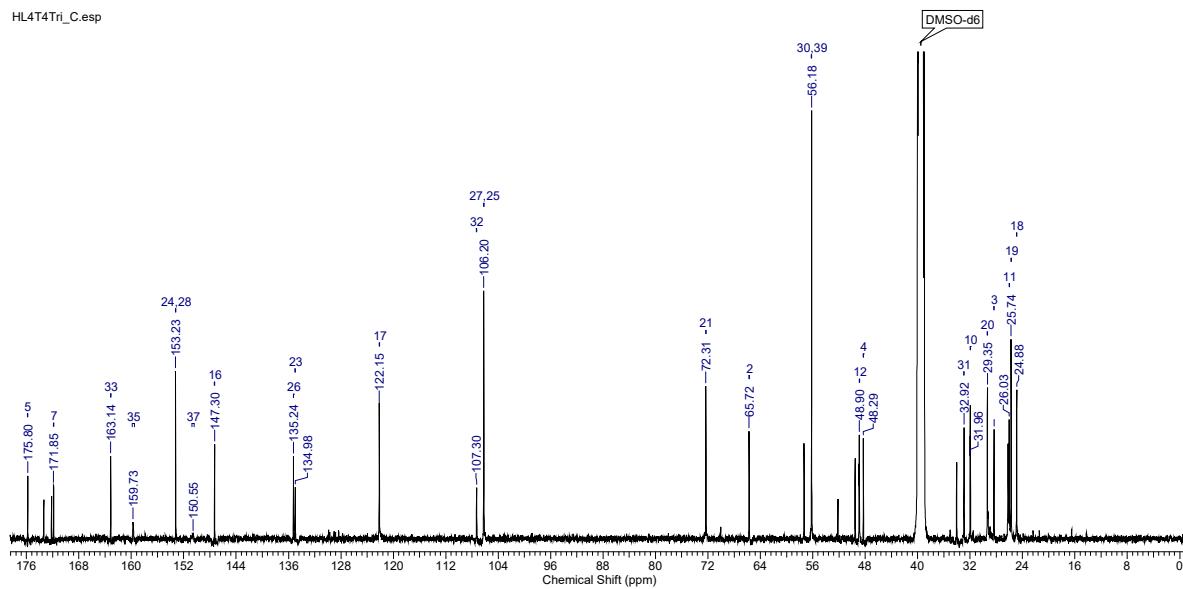
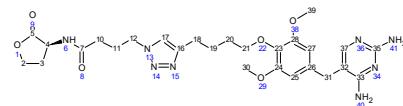
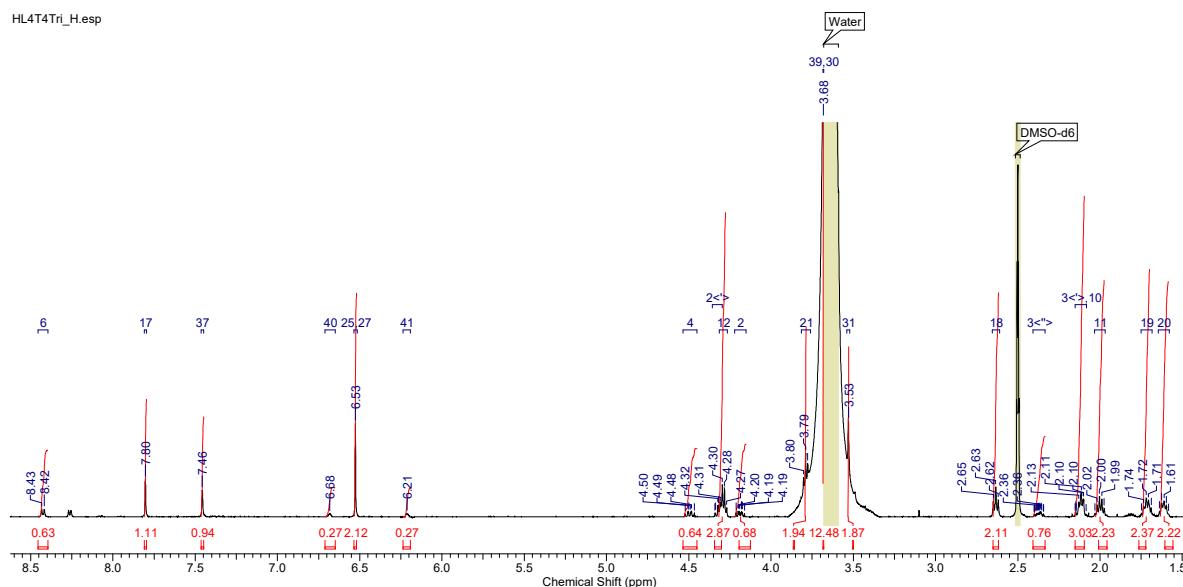
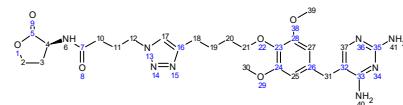
10.10 (*S*)-1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(4-(1-(6-oxo-6-((2-oxotetrahydrofuran-3-yl)amino)hexyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 76



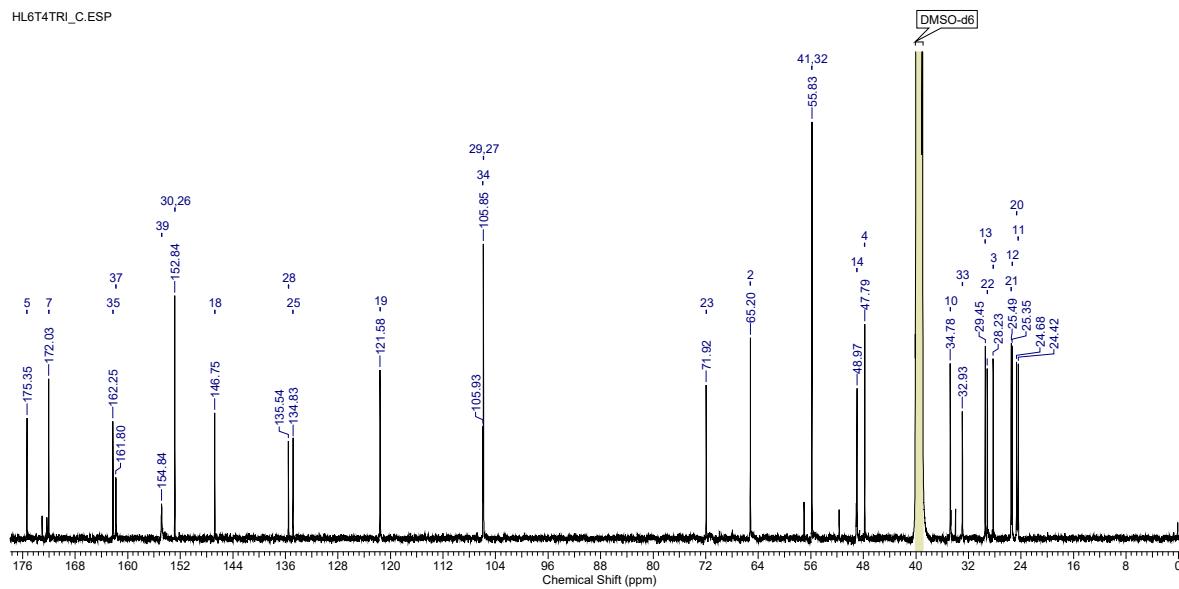
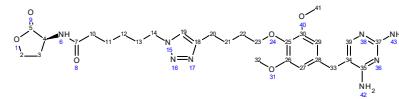
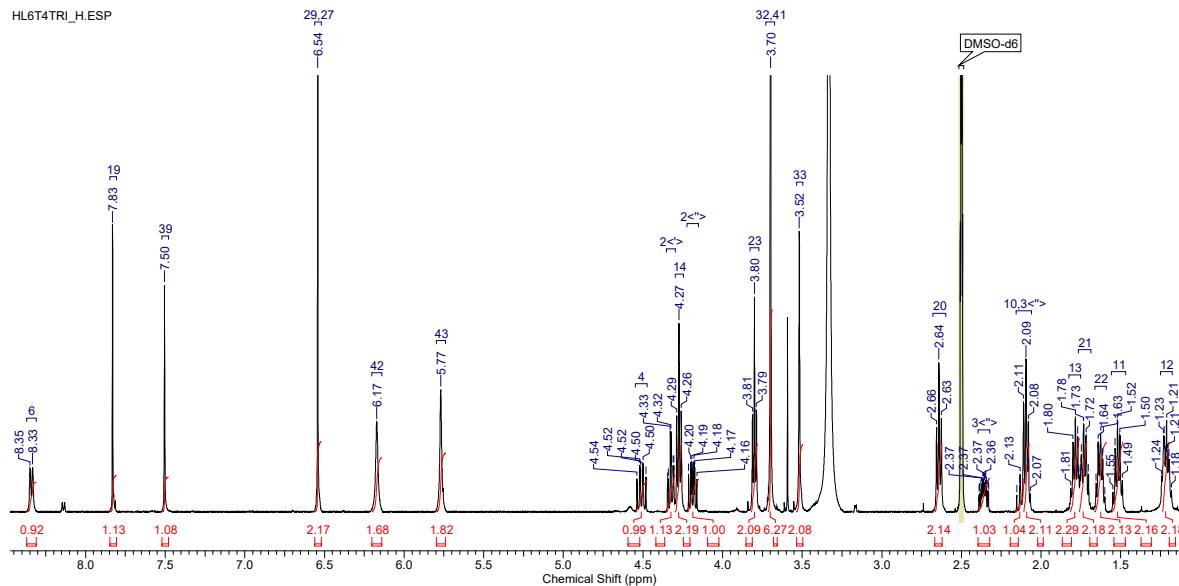
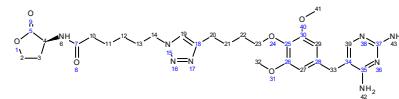
10.11 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(2-heptyl-4-oxo-1,4-dihydroquinolin-6-yl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 78



10.12 (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 82

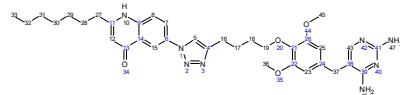


10.13 (*S*)-6-((4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1*H*-1,2,3-triazol-1-yl)-*N*-(2-oxotetrahydrofuran-3-yl)hexanamide 83

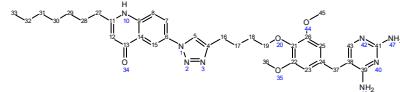
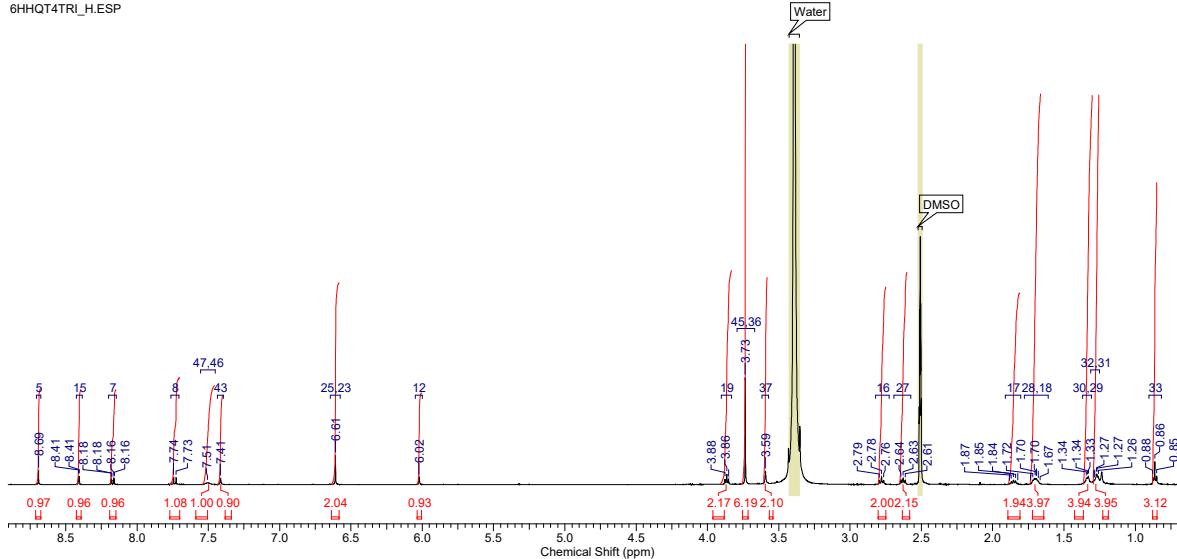


10.14 6-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1*H*-1,2,3-triazol-1-yl)-2-heptylquinolin-4(*1H*)-one 85

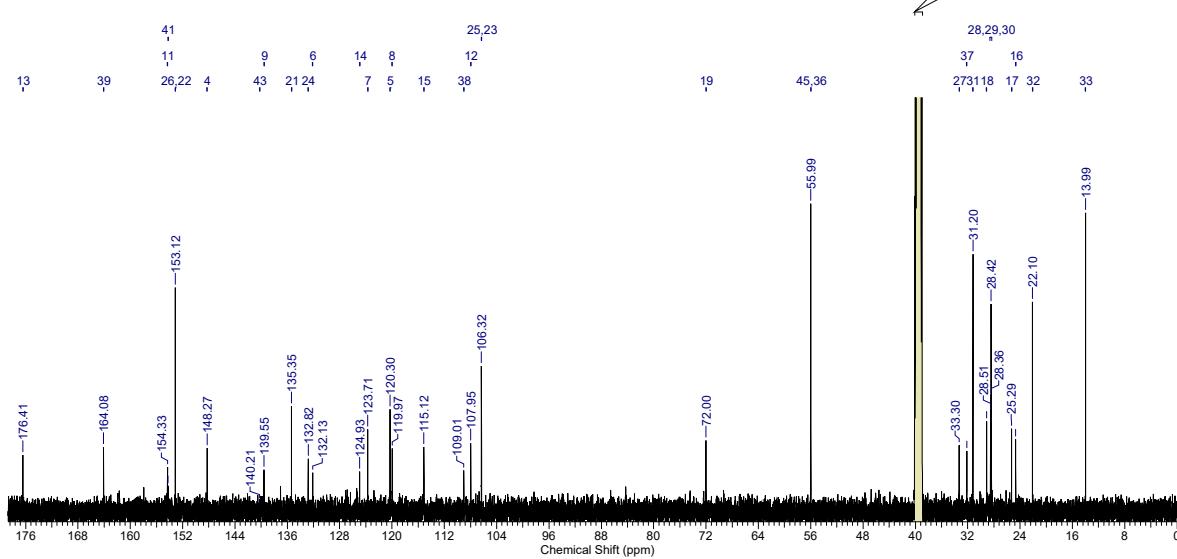
User Notes Some guesses



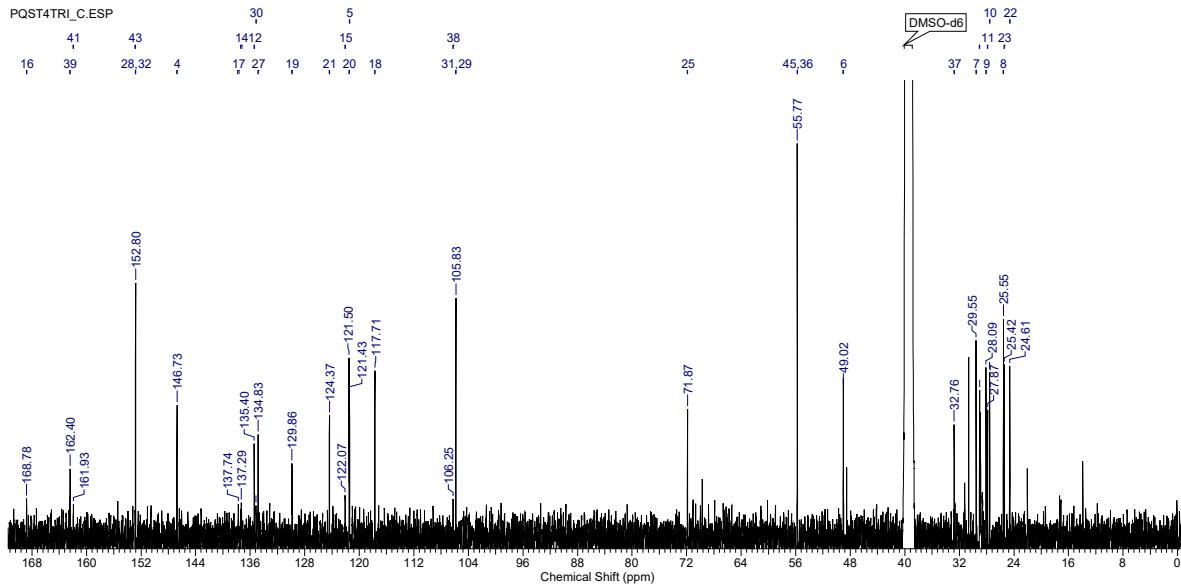
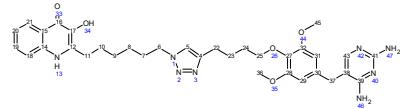
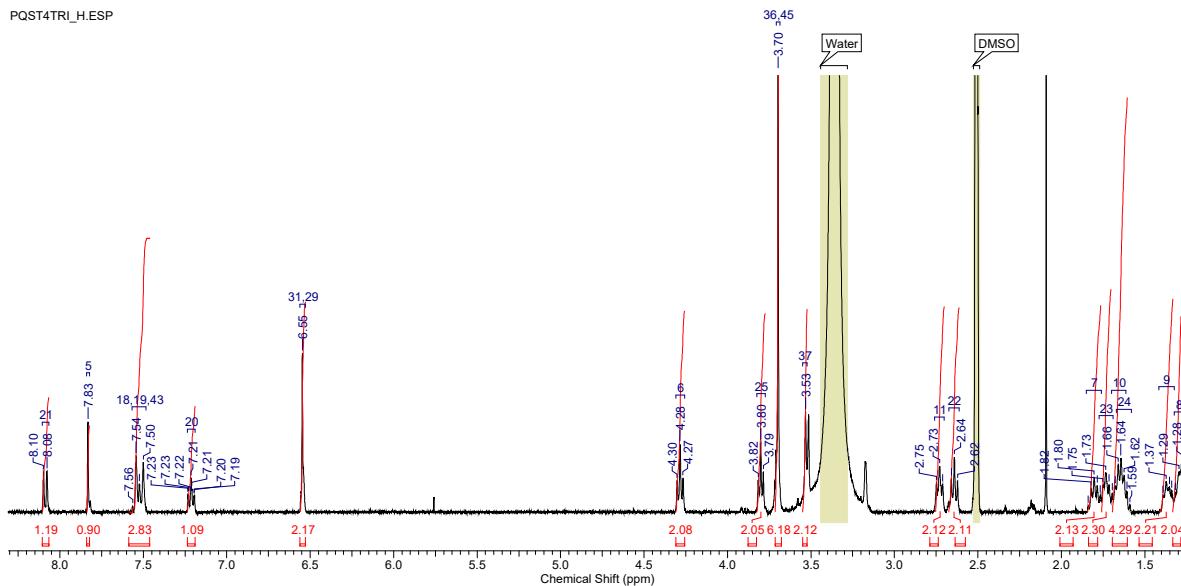
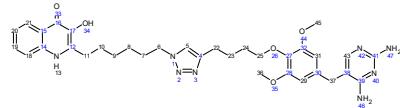
6HHQT4TRI H.ESP



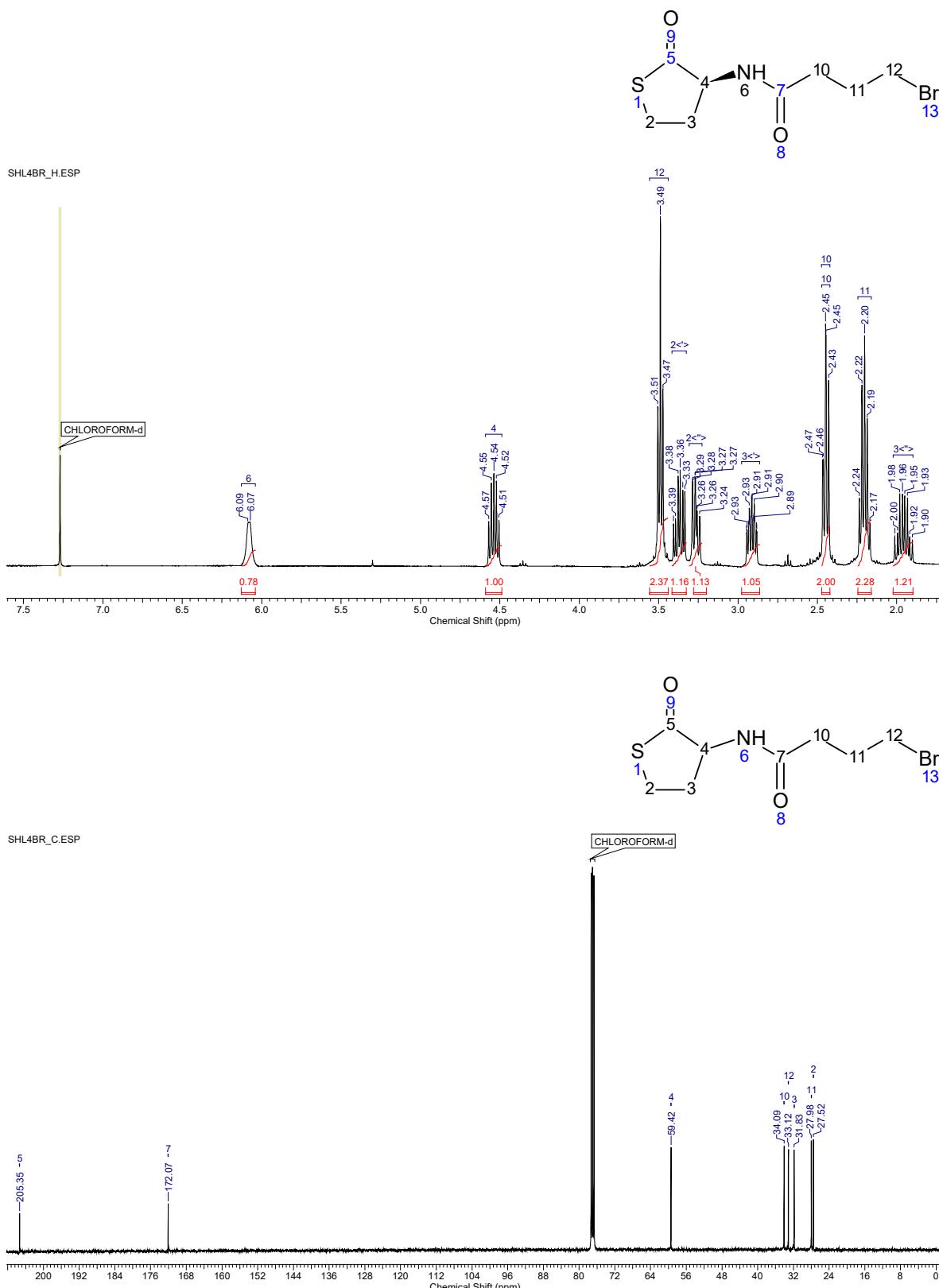
6HHQT4TRI_C.ESP



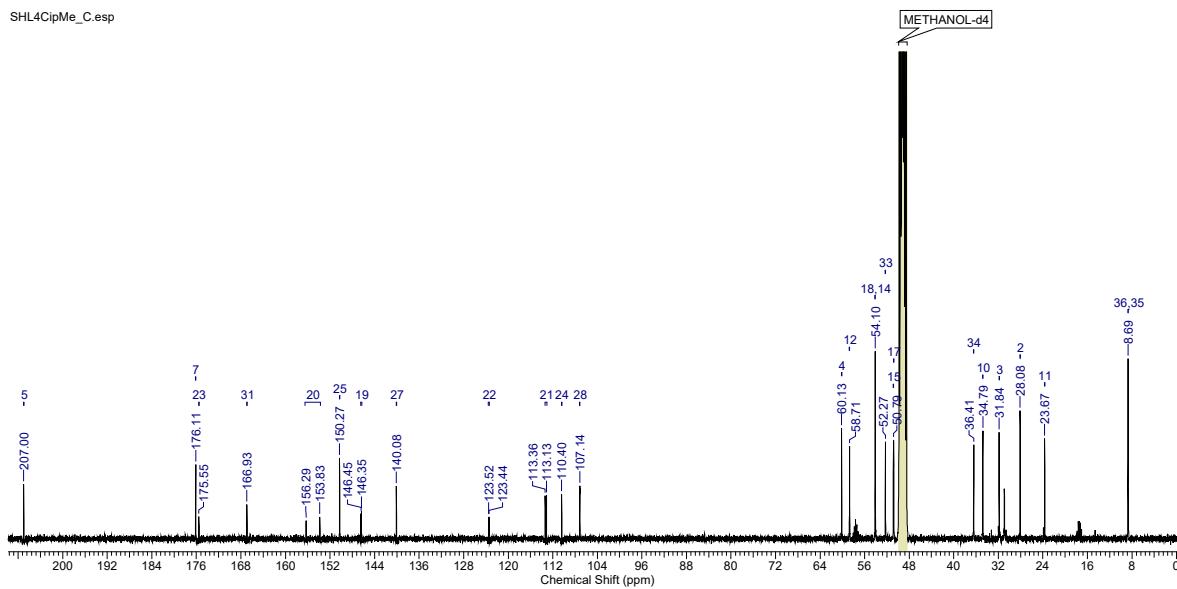
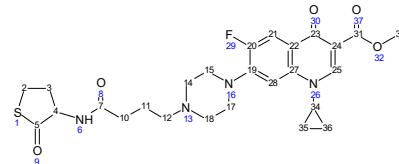
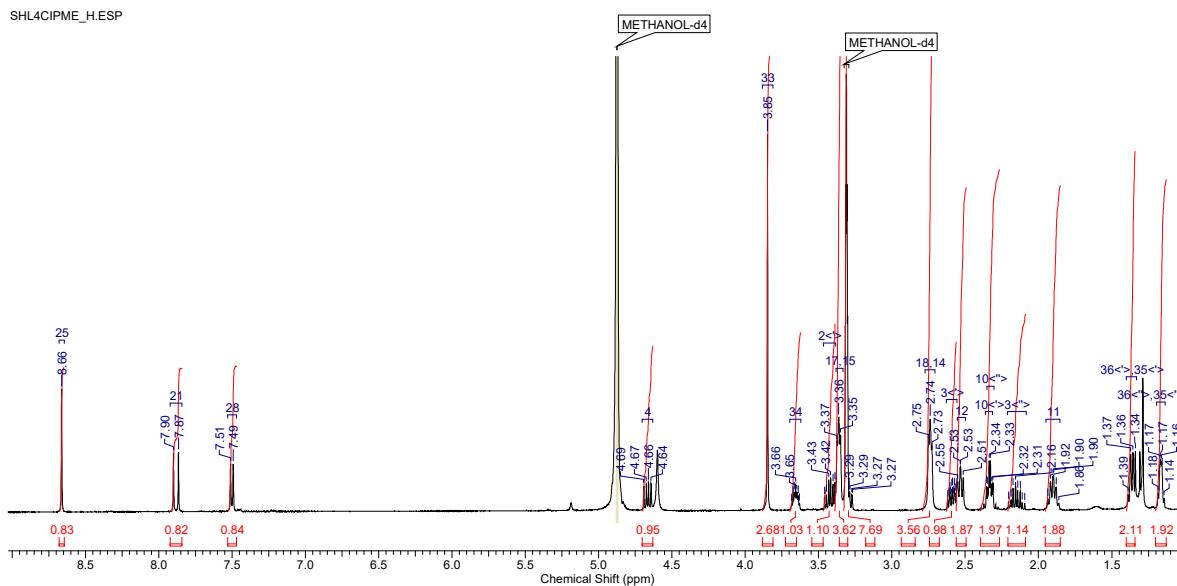
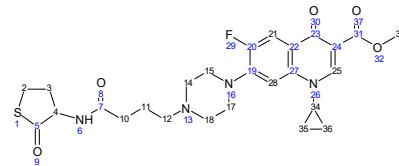
10.15 2-(6-(4-(4-(4-((2,4-Diaminopyrimidin-5-yl)methyl)-2,6-dimethoxyphenoxy)butyl)-1*H*-1,2,3-triazol-1-yl)hexyl)-3-hydroxyquinolin-4(*1H*)-one 87



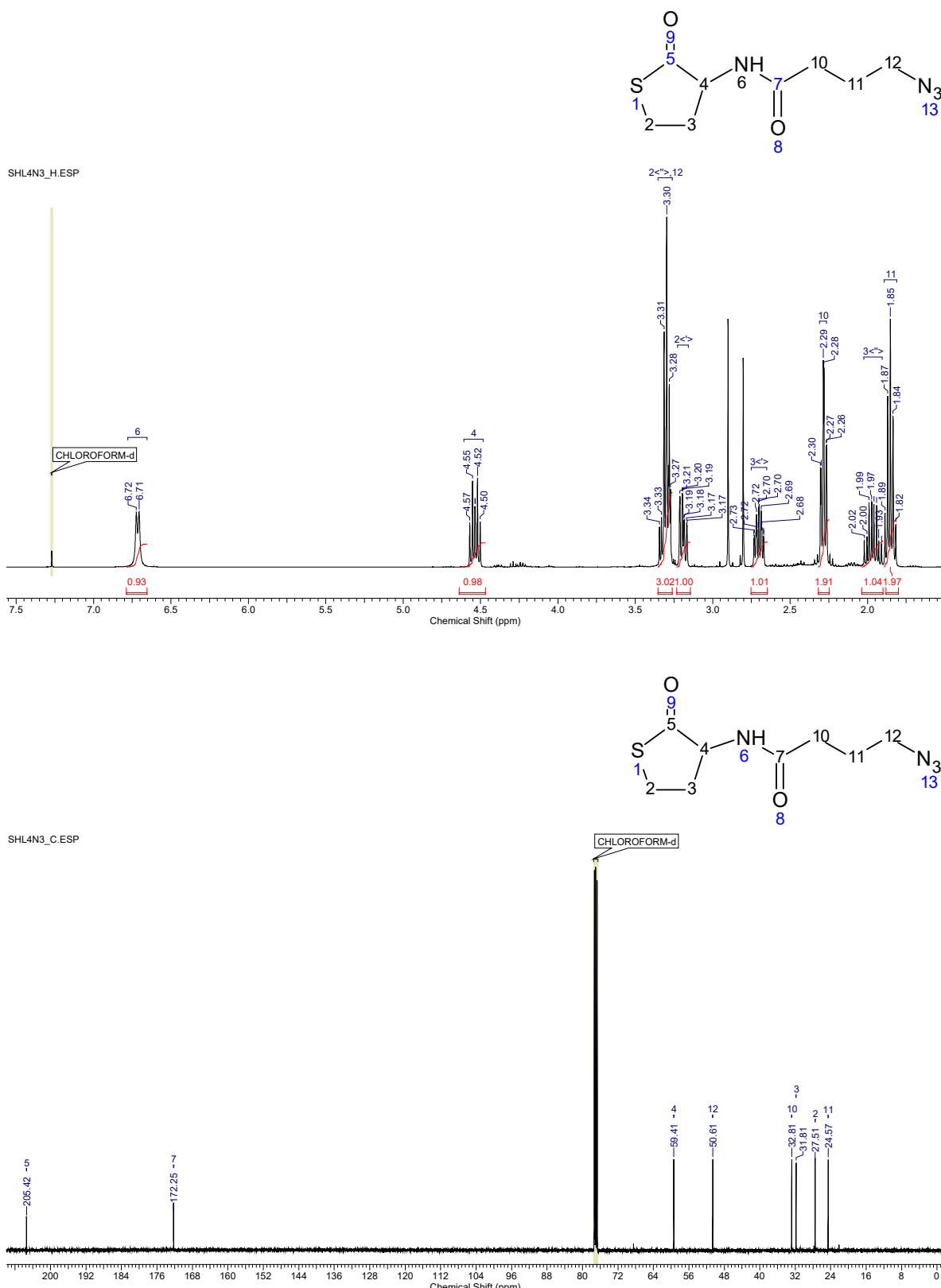
10.16 4-Bromo-N-(2-oxotetrahydrothiophen-3-yl)butanamide 100



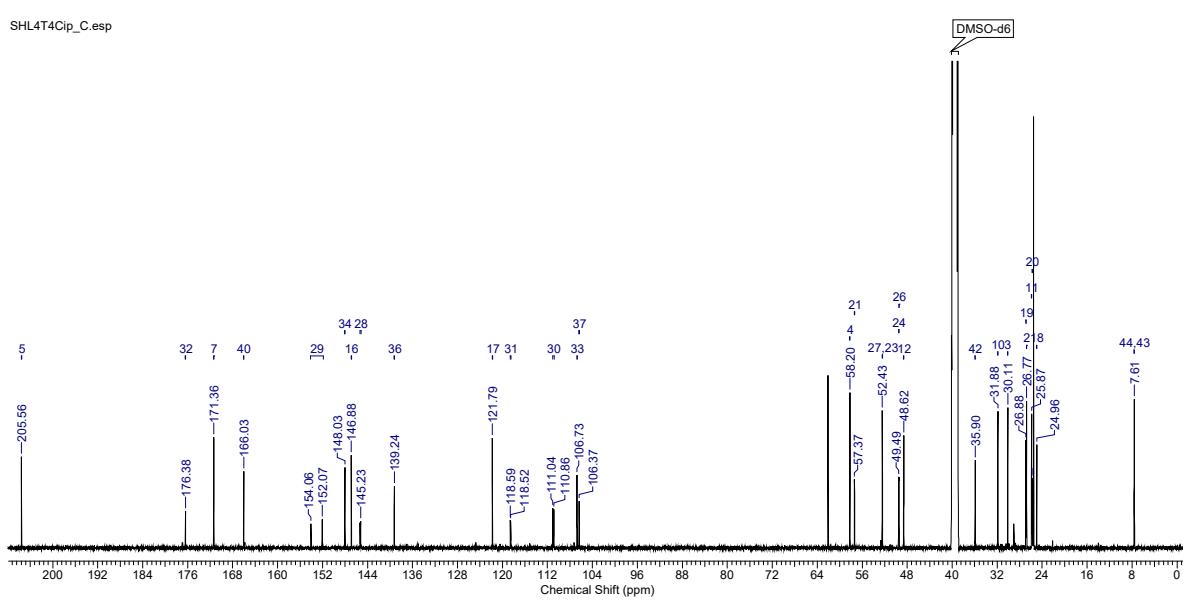
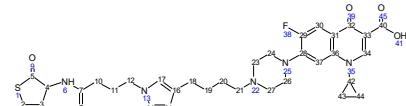
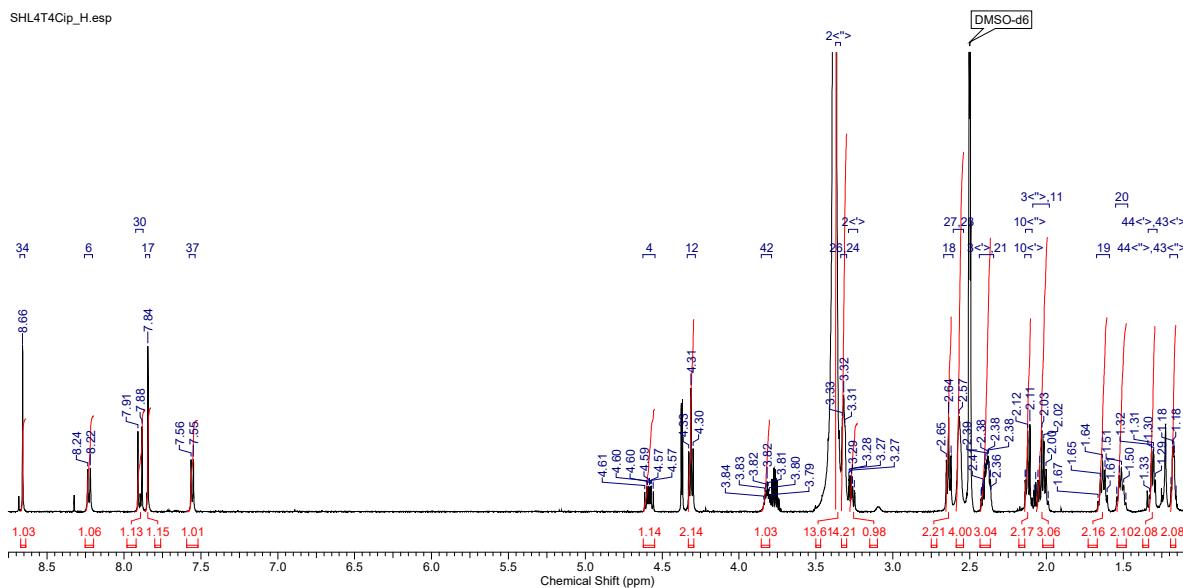
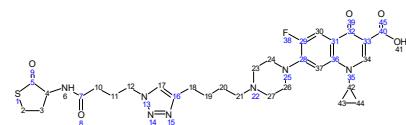
10.17 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 101



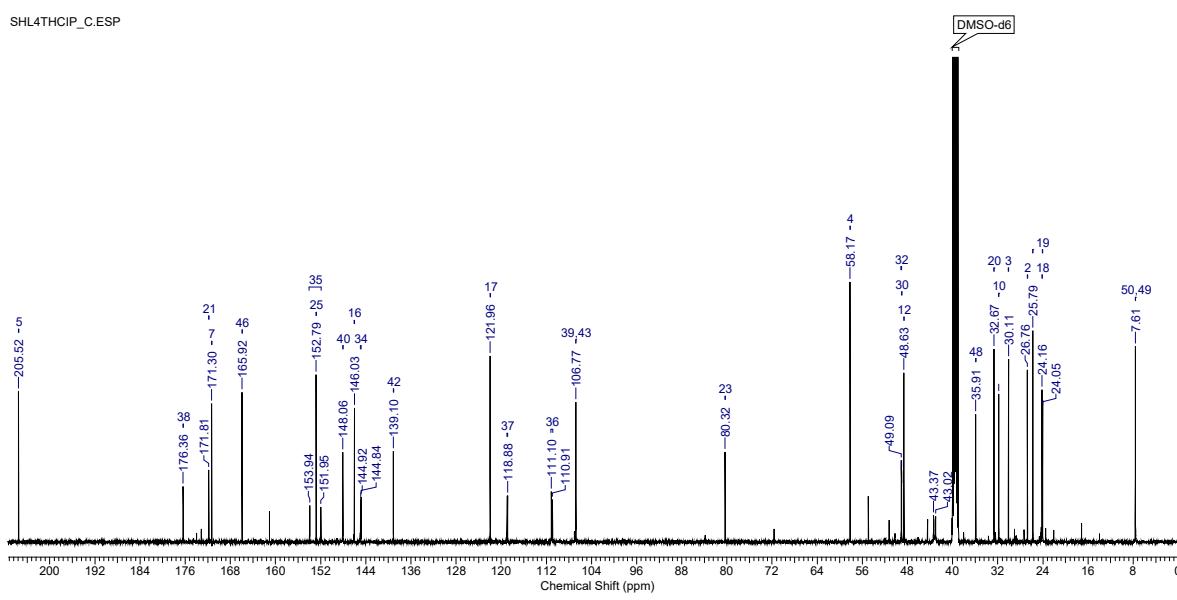
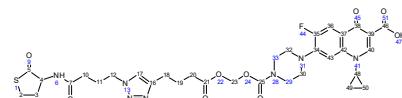
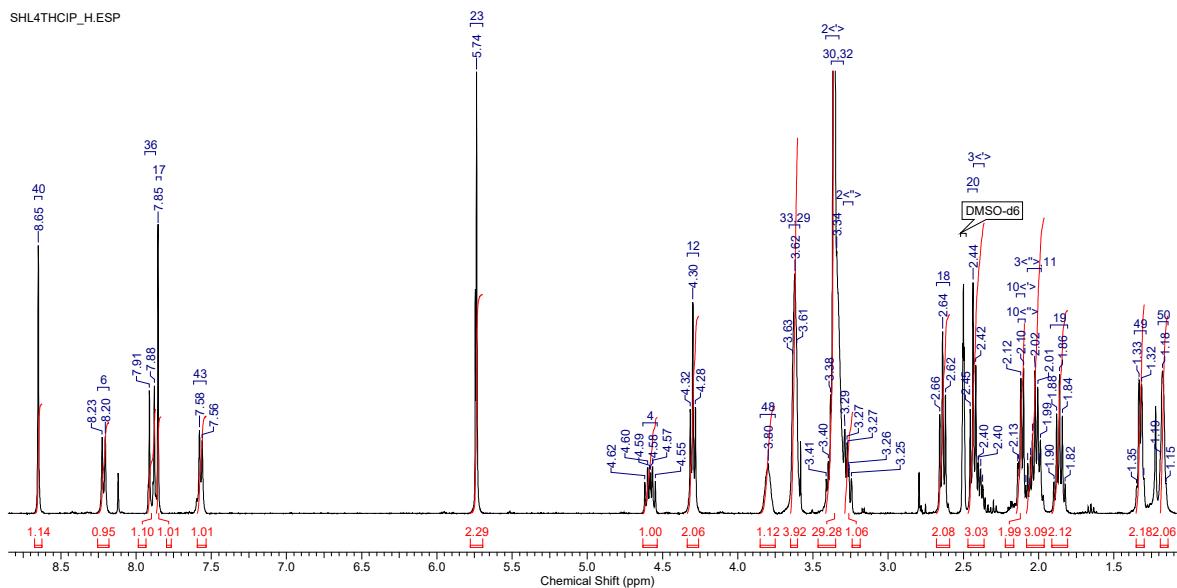
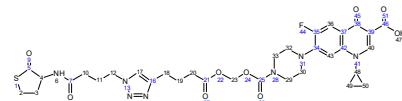
10.18 4-Azido-*N*-(2-oxotetrahydrothiophen-3-yl)butanamide 102



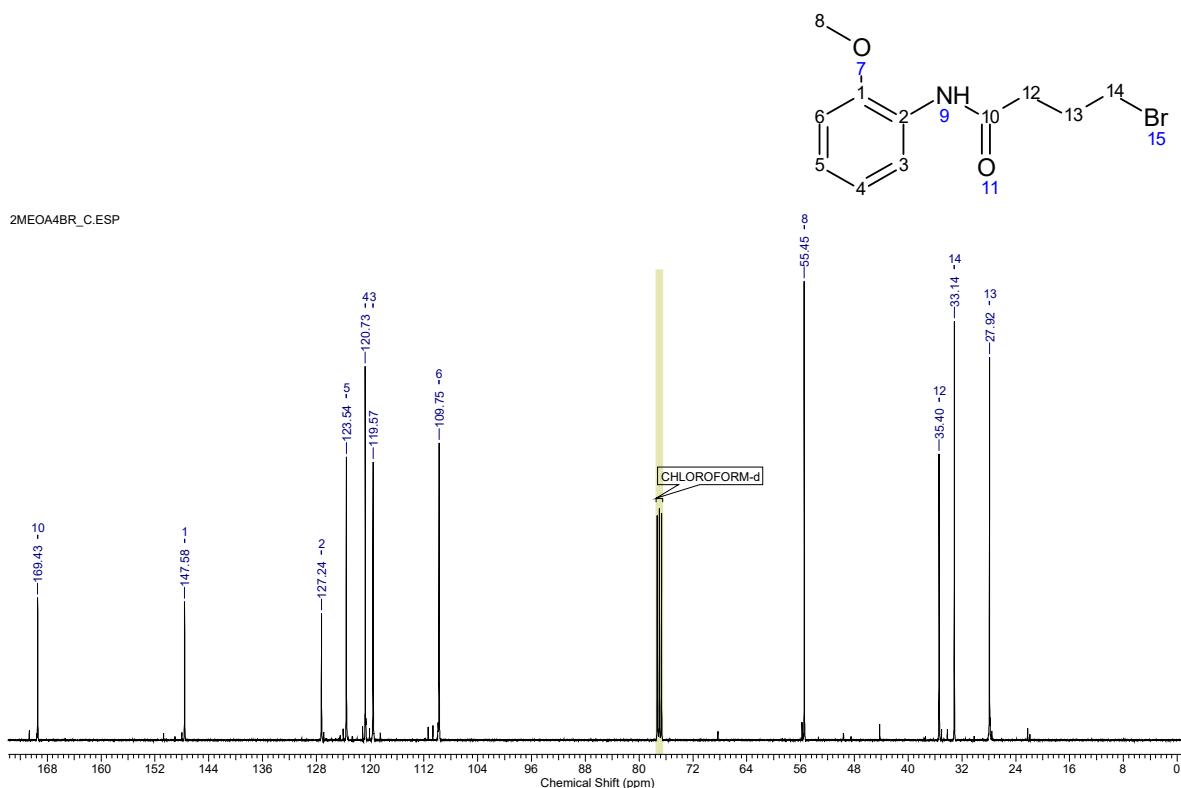
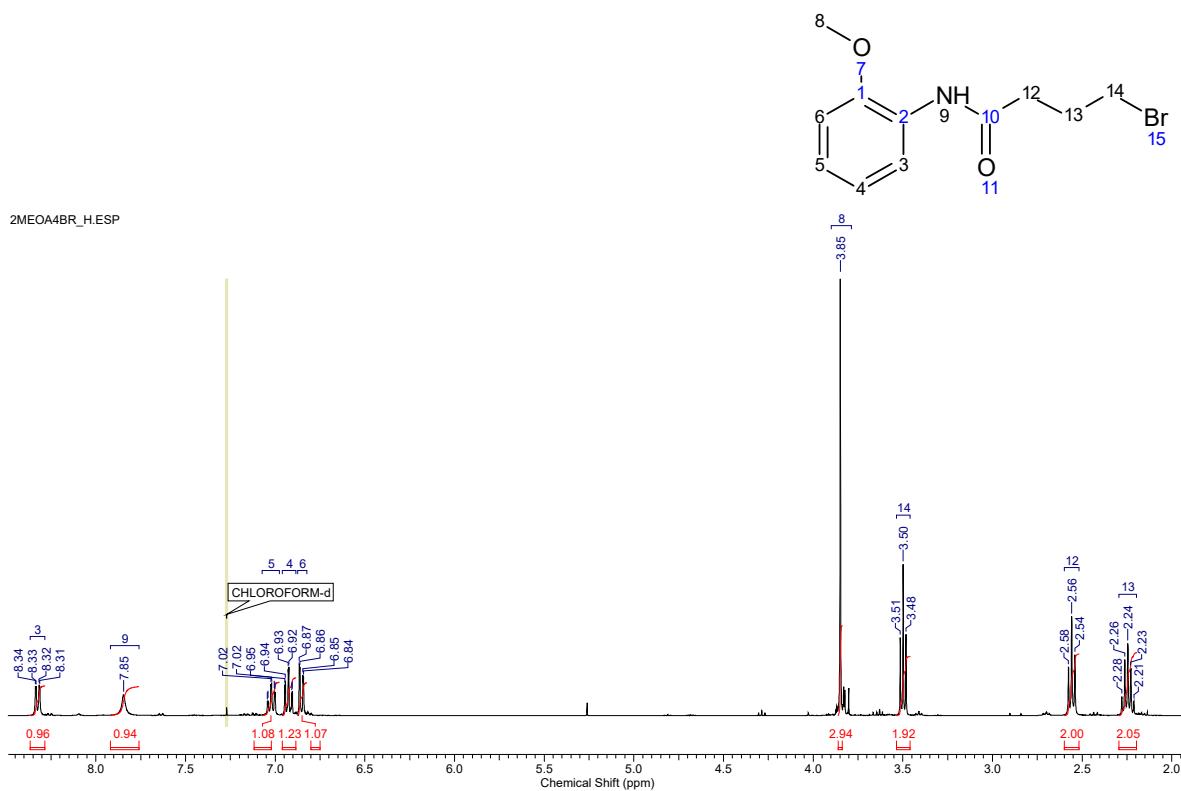
10.19 1-Cyclopropyl-6-fluoro-4-oxo-7-(4-(1-(4-oxo-4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 103



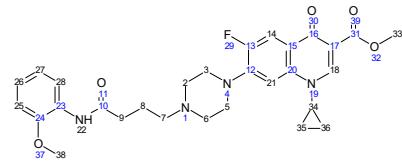
10.20 1-Cyclopropyl-6-fluoro-4-oxo-7-((4-((4-((2-oxotetrahydrothiophen-3-yl)amino)butyl)-1*H*-1,2,3-triazol-4-yl)butanoyl)oxy)methoxy)carbonyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylic acid 104



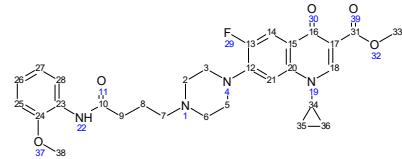
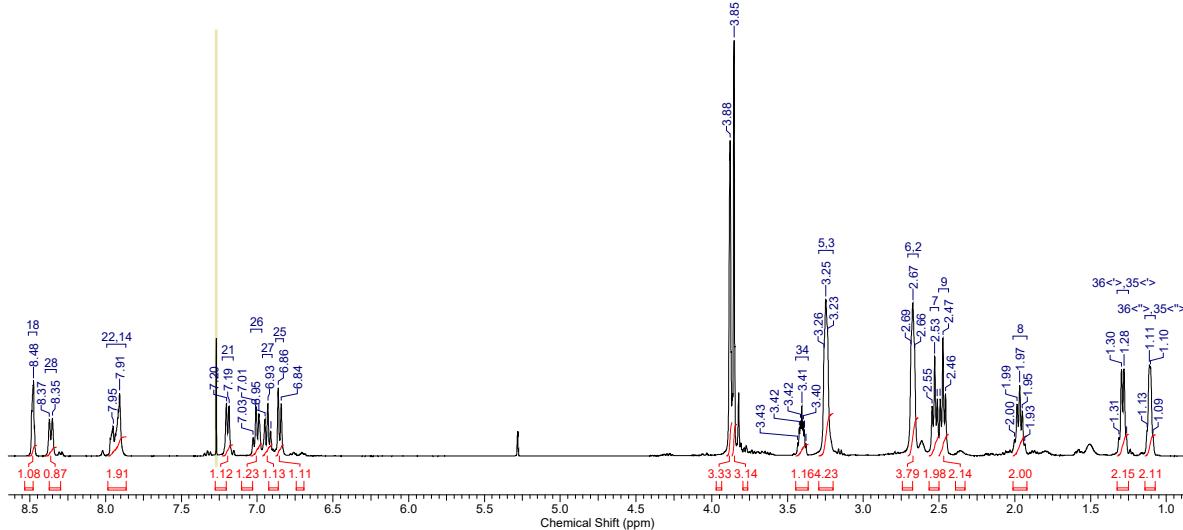
10.21 4-Bromo-N-(2-methoxyphenyl)butanamide 106



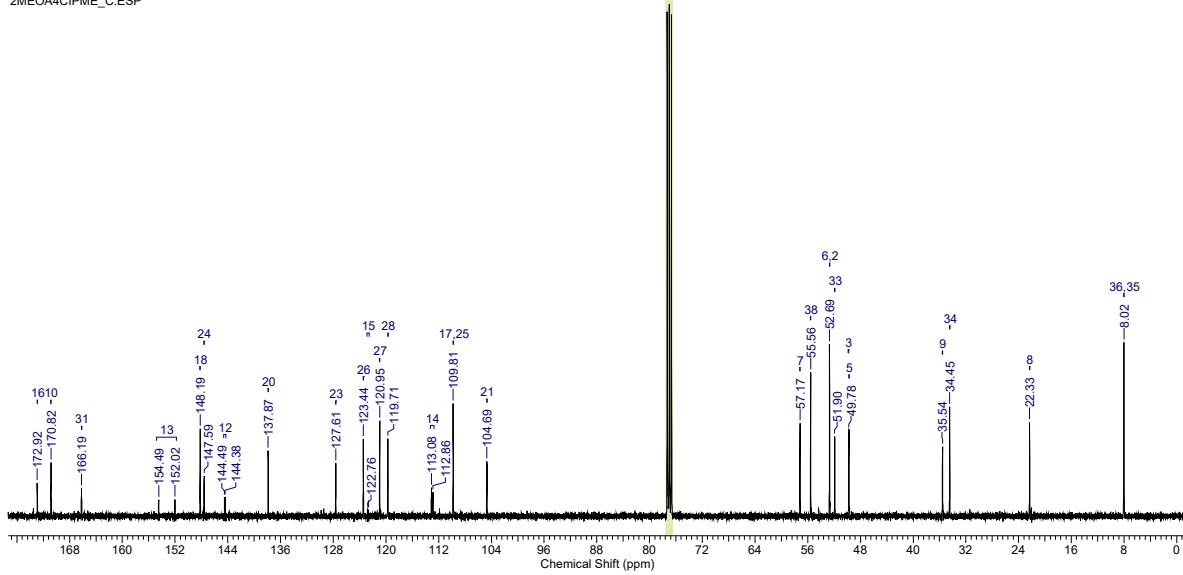
10.22 Methyl 1-cyclopropyl-6-fluoro-7-(4-((2-methoxyphenyl)amino)-4-oxobutyl)-piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 107



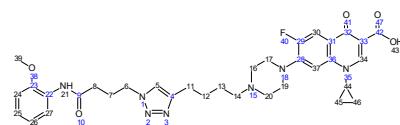
2MEOA4CIPME_H.ESP



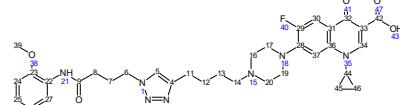
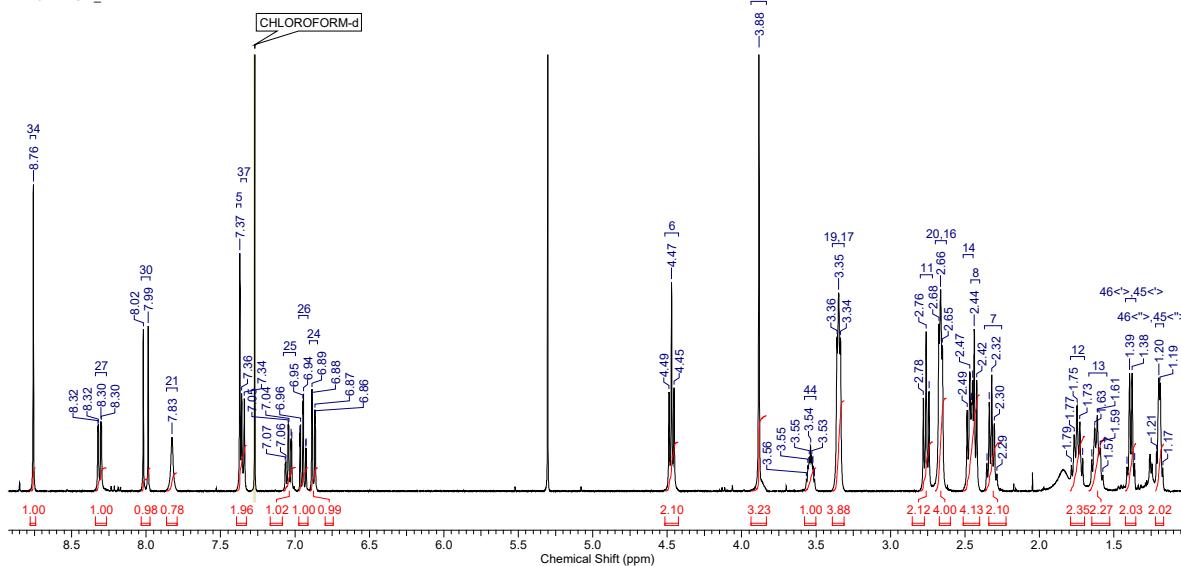
2MEOA4CIPME_C.ESP



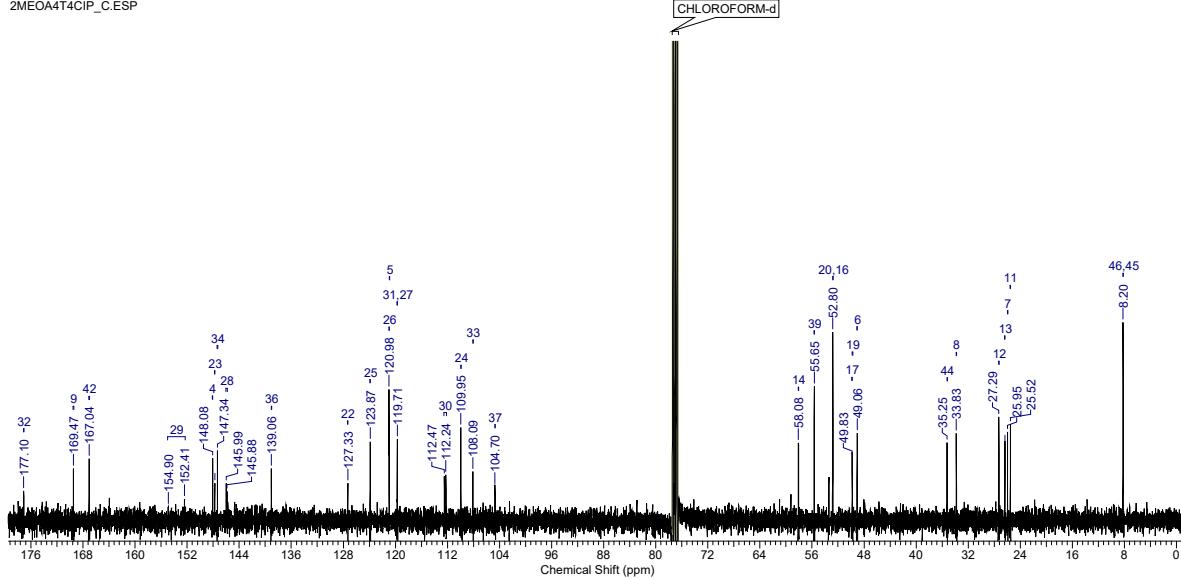
10.23 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((2-methoxyphenyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl) piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 109



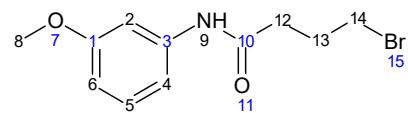
2MEOA4T4CIP_H_ESP



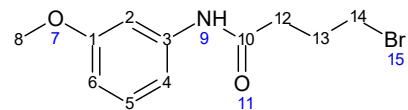
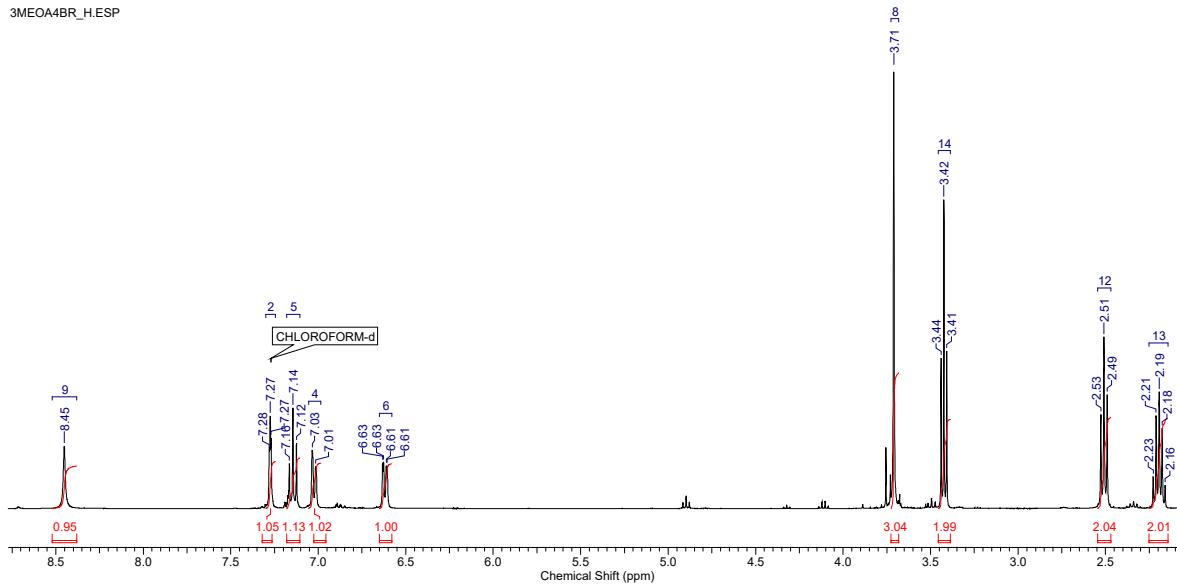
2MEOA4T4CIP_C_ESP



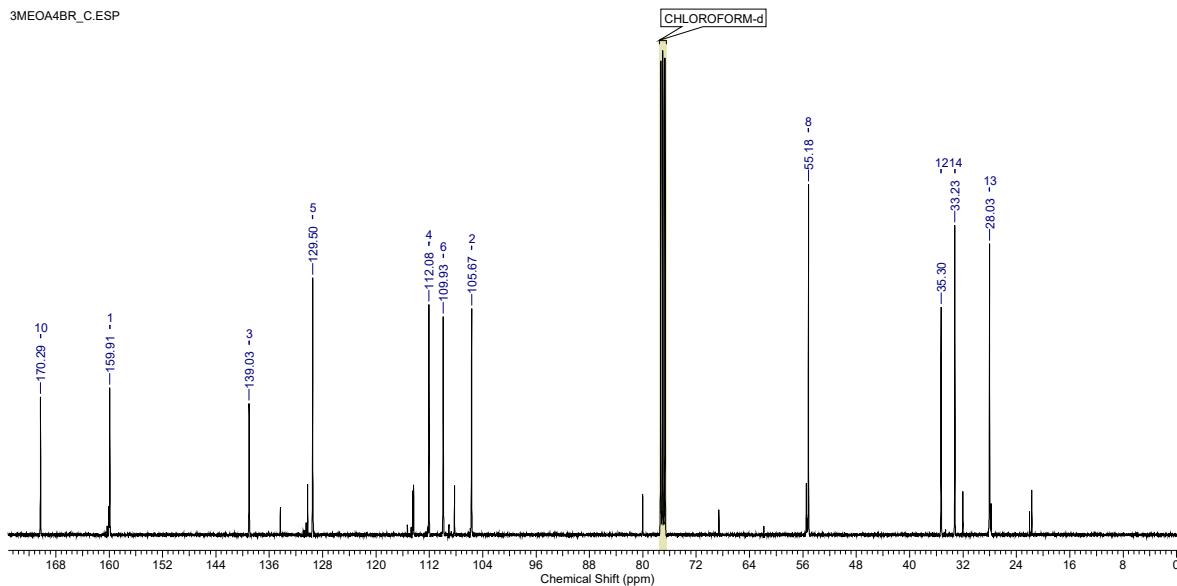
10.24 4-Bromo-N-(3-methoxyphenyl)butanamide 111



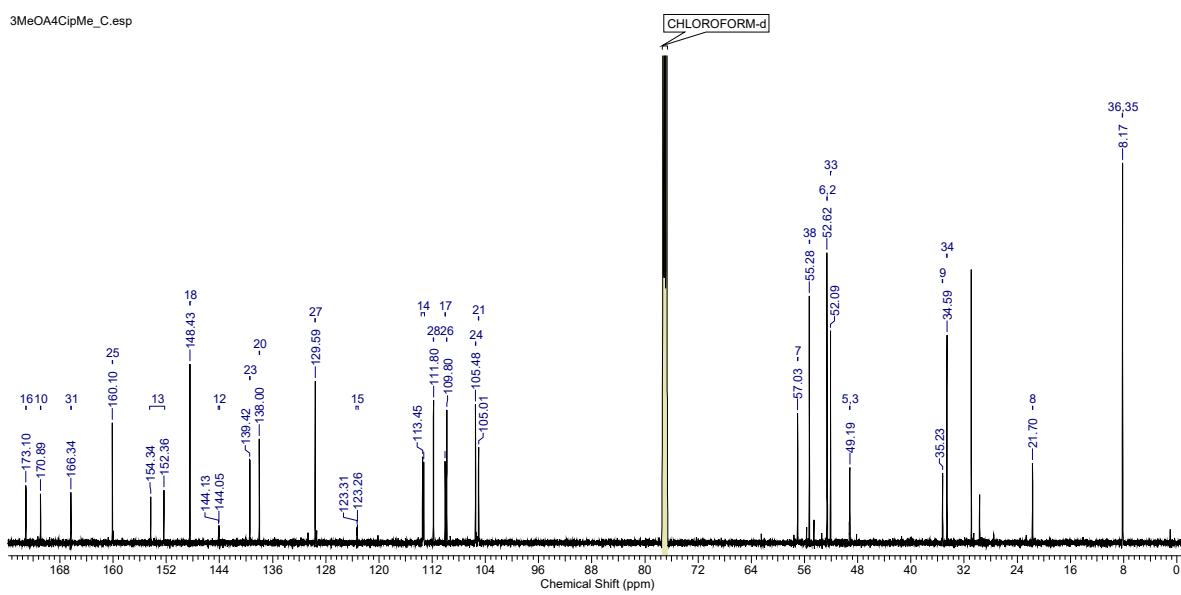
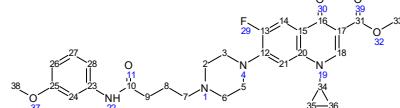
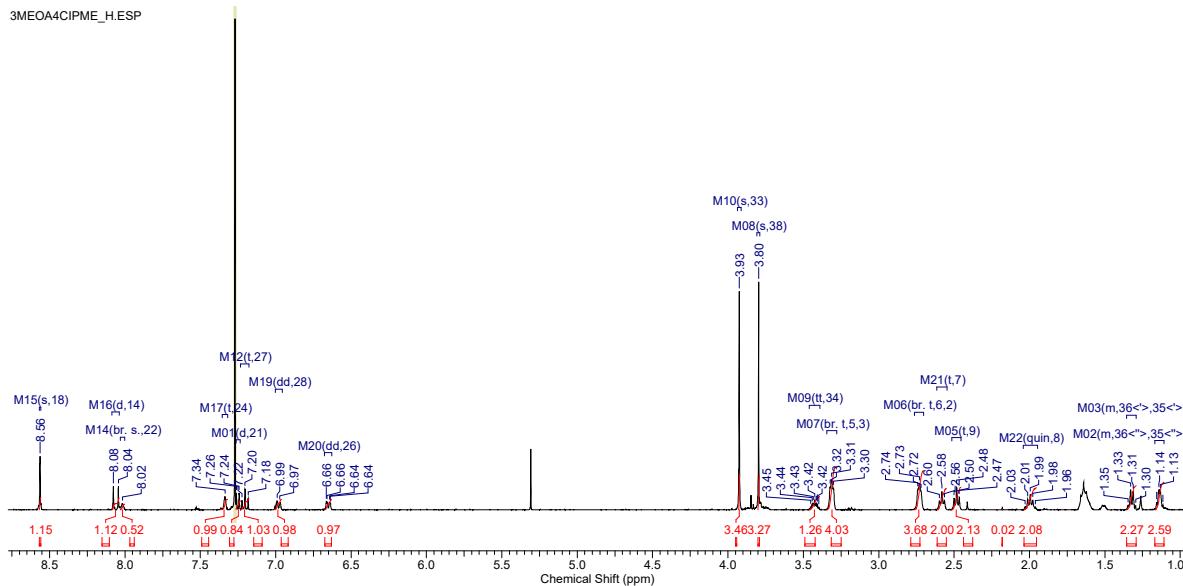
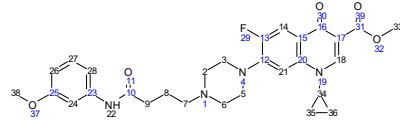
3MEOA4BR_H.ESP



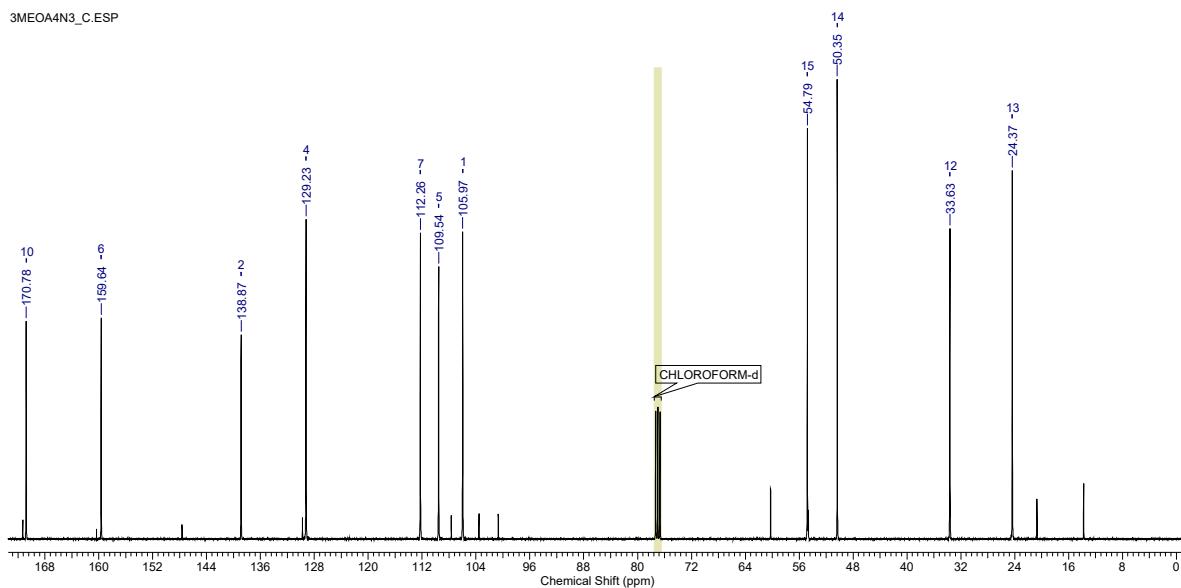
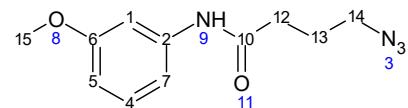
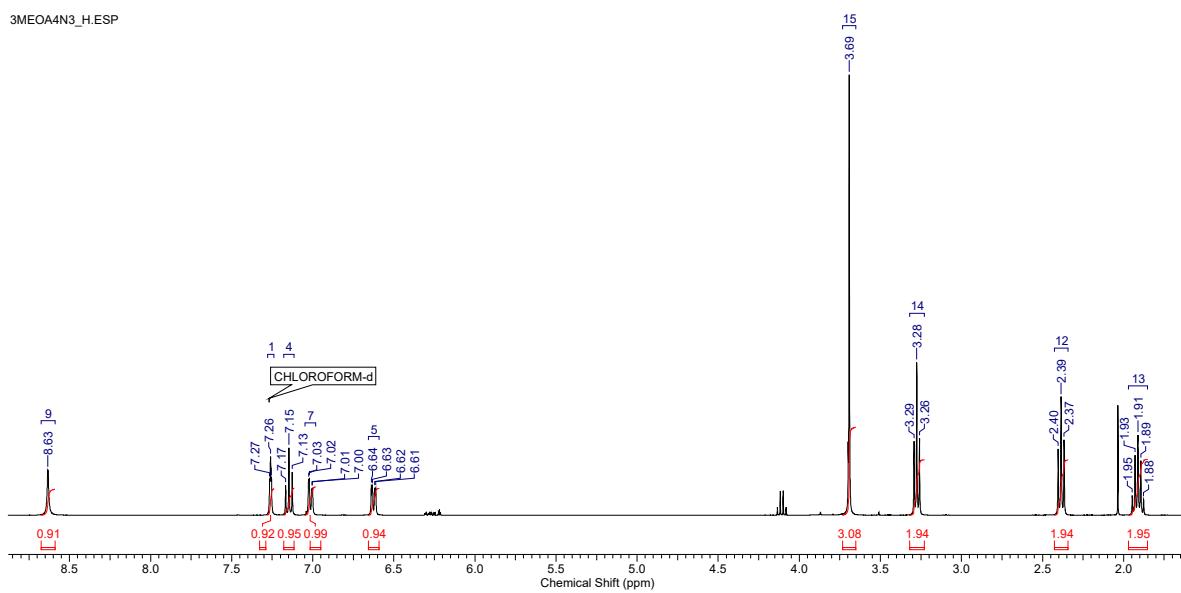
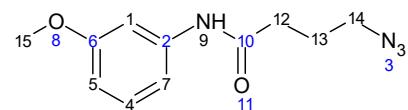
3MEOA4BR_C.ESP



10.25 Methyl 1-cyclopropyl-6-fluoro-7-(4-((3-methoxyphenyl)amino)-4-oxobutyl)-piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 112



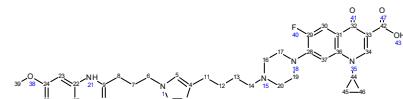
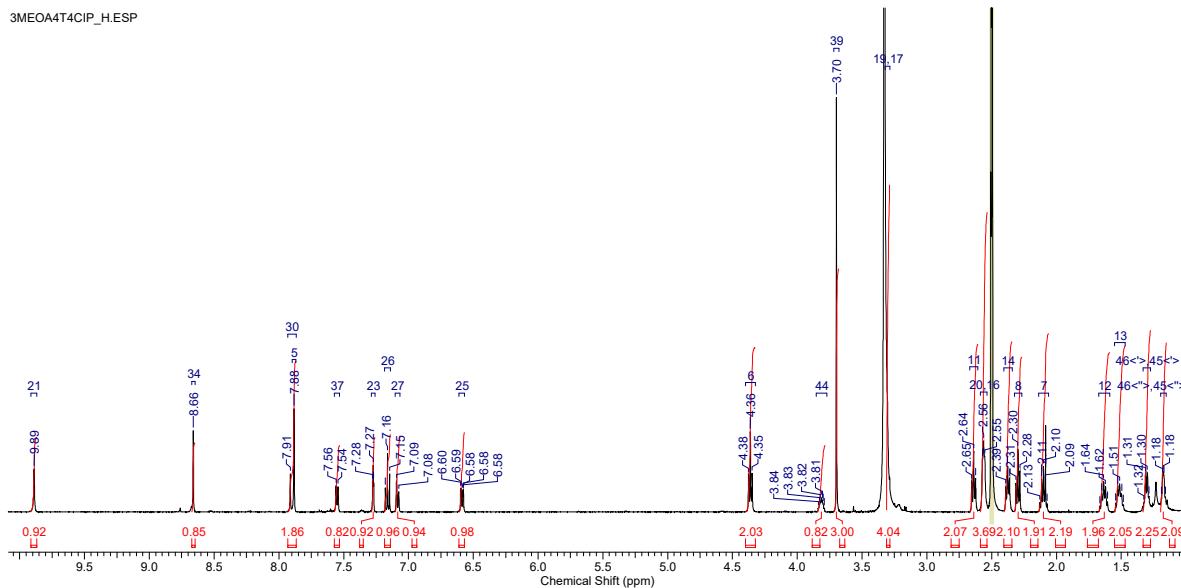
10.26 4-Azido-*N*-(3-methoxyphenyl)butanamide 113



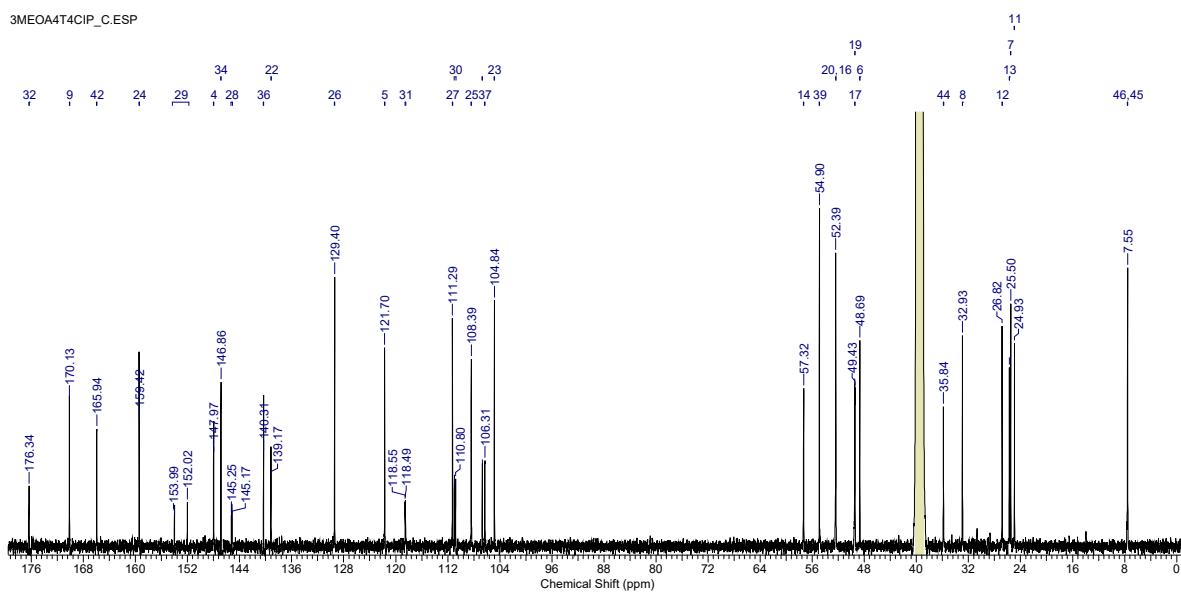
10.27 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-((3-methoxyphenyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 114



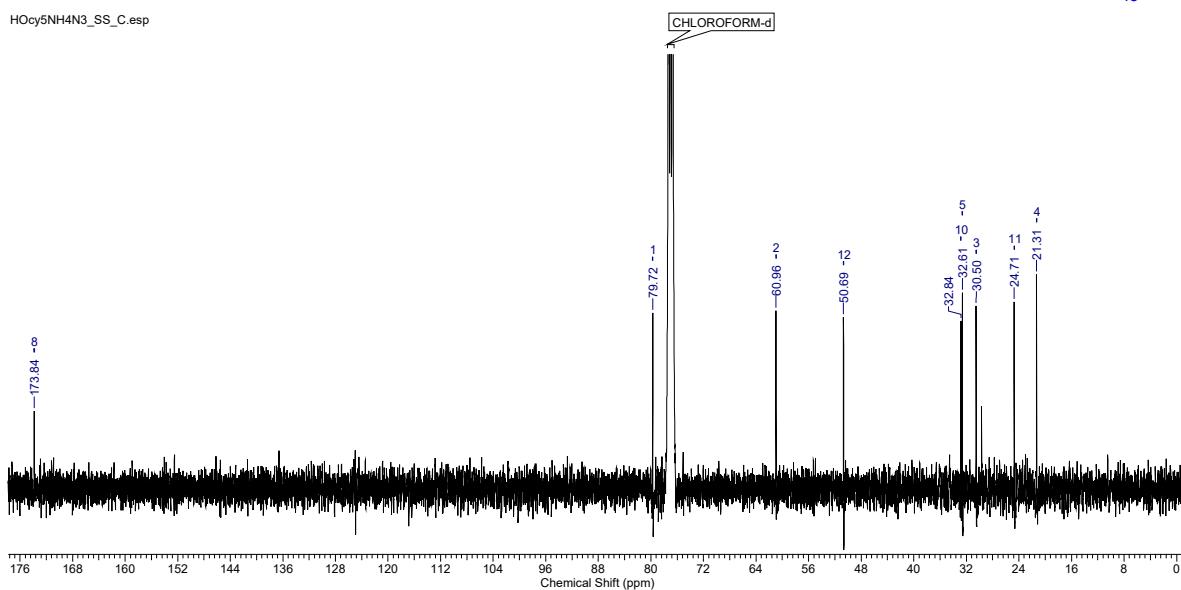
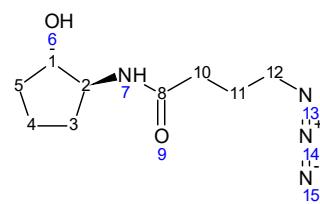
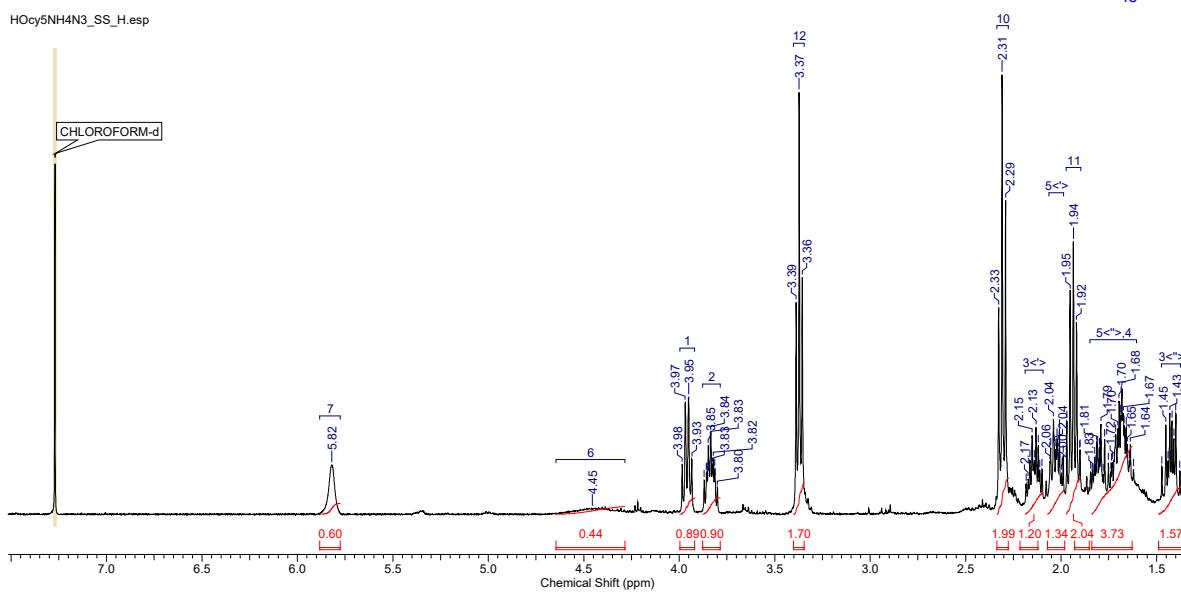
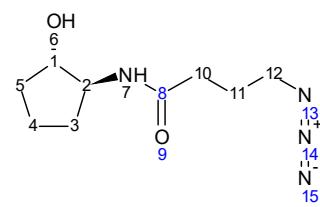
3MEOA4T4CIP_H_ESP



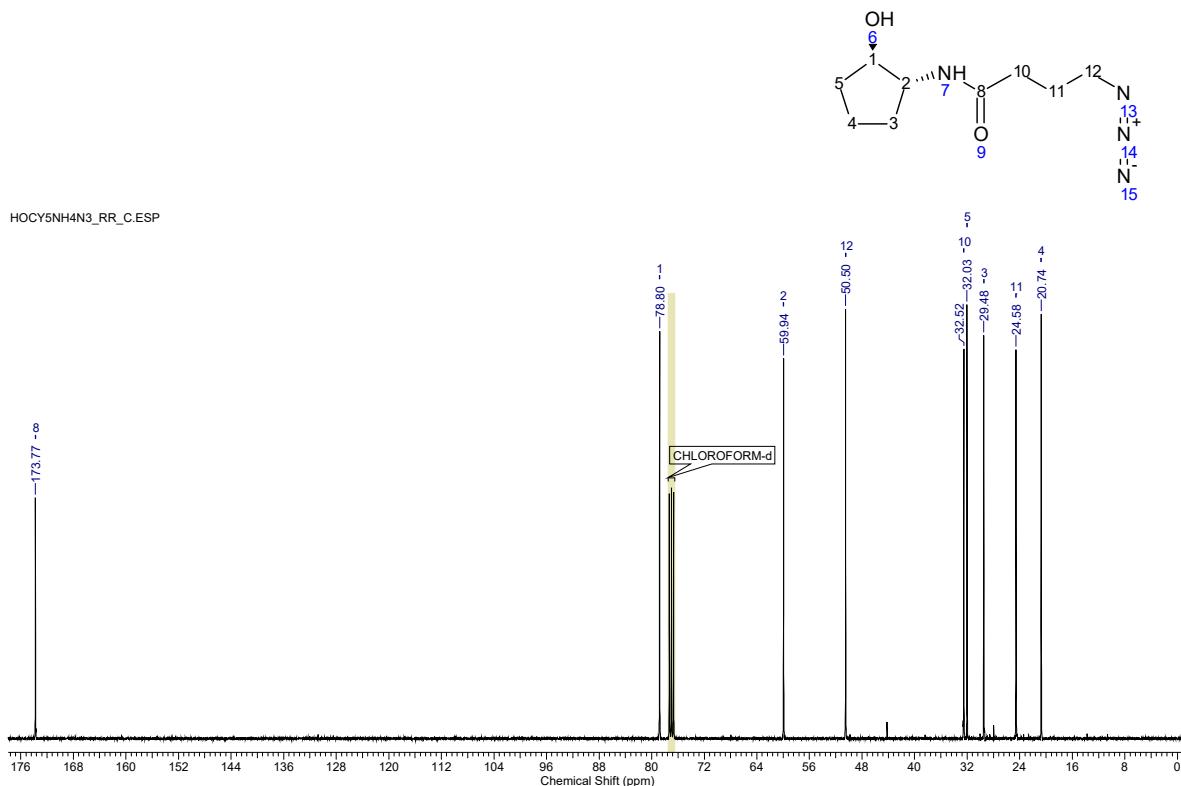
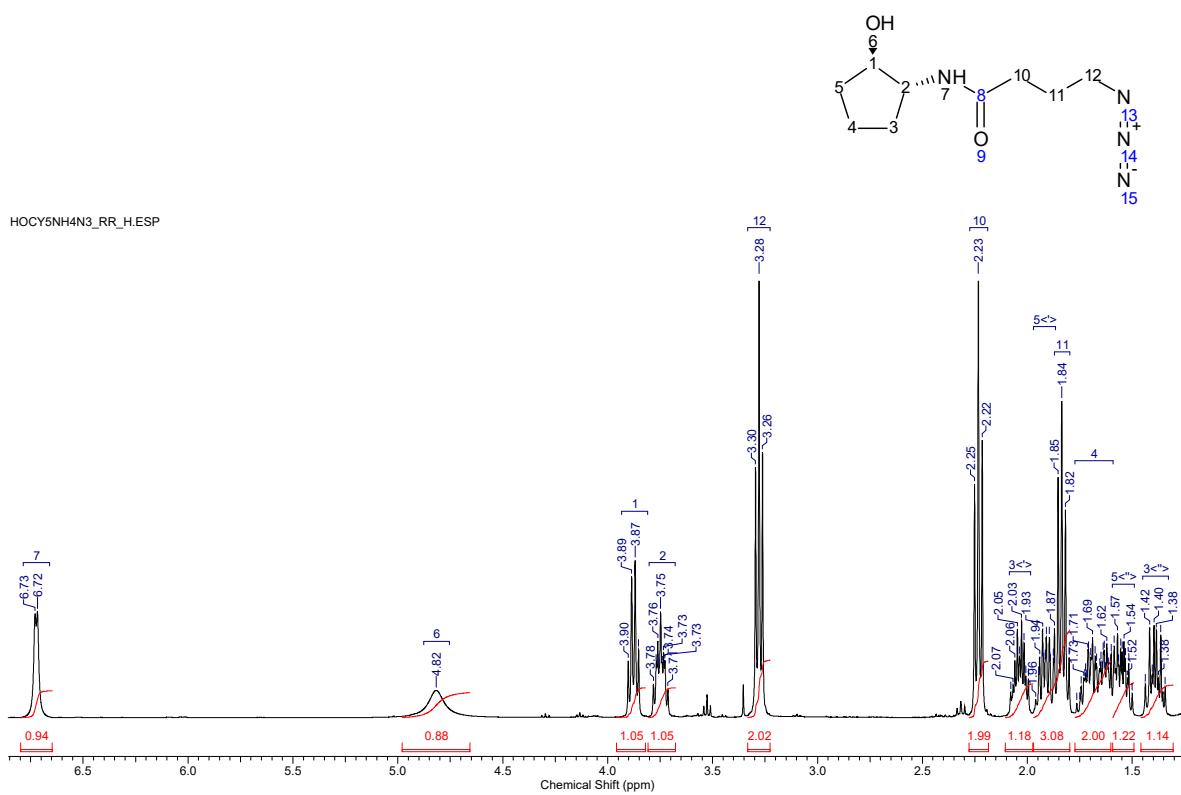
3MEOA4T4CIP_C_ESP



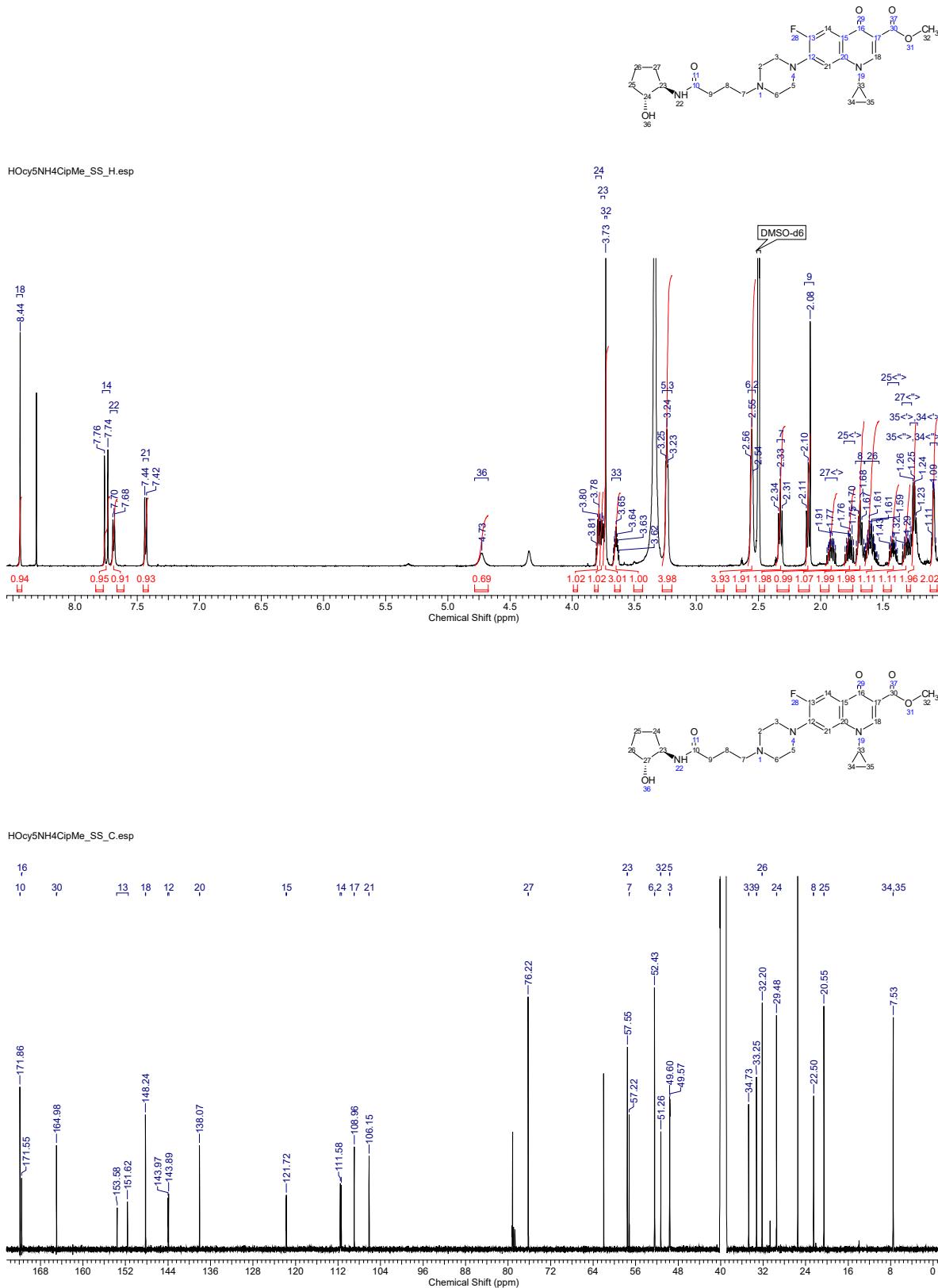
10.28 4-Azido-*N*-(*1S,2S*)-2-hydroxycyclopentyl)butanamide 123



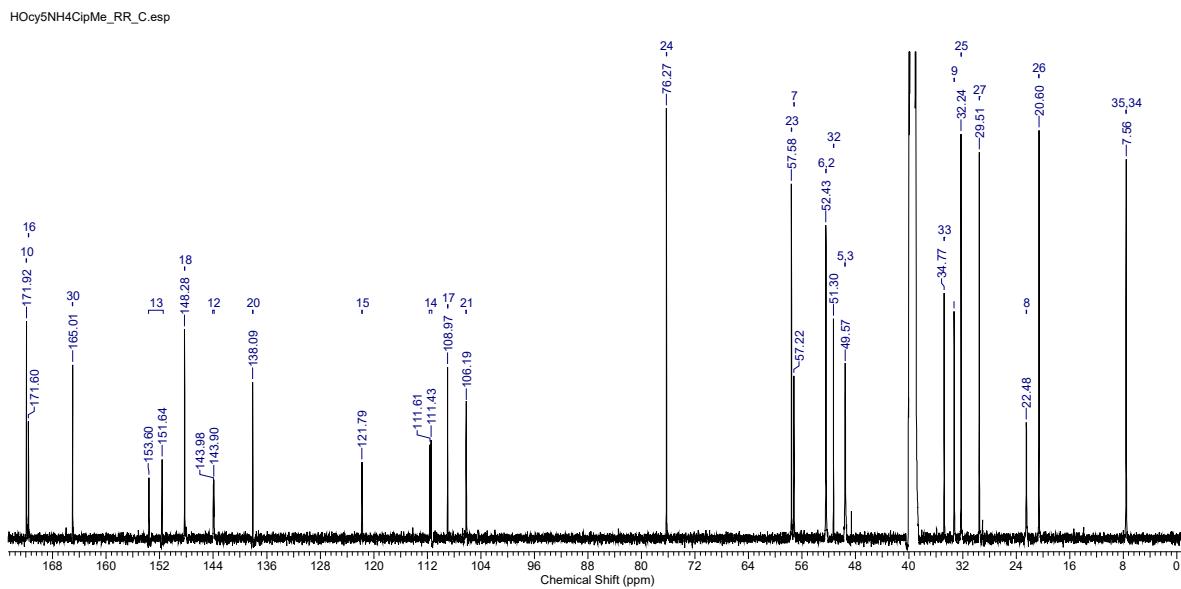
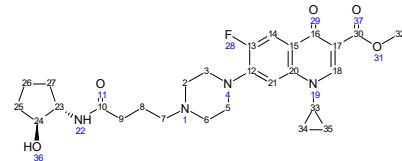
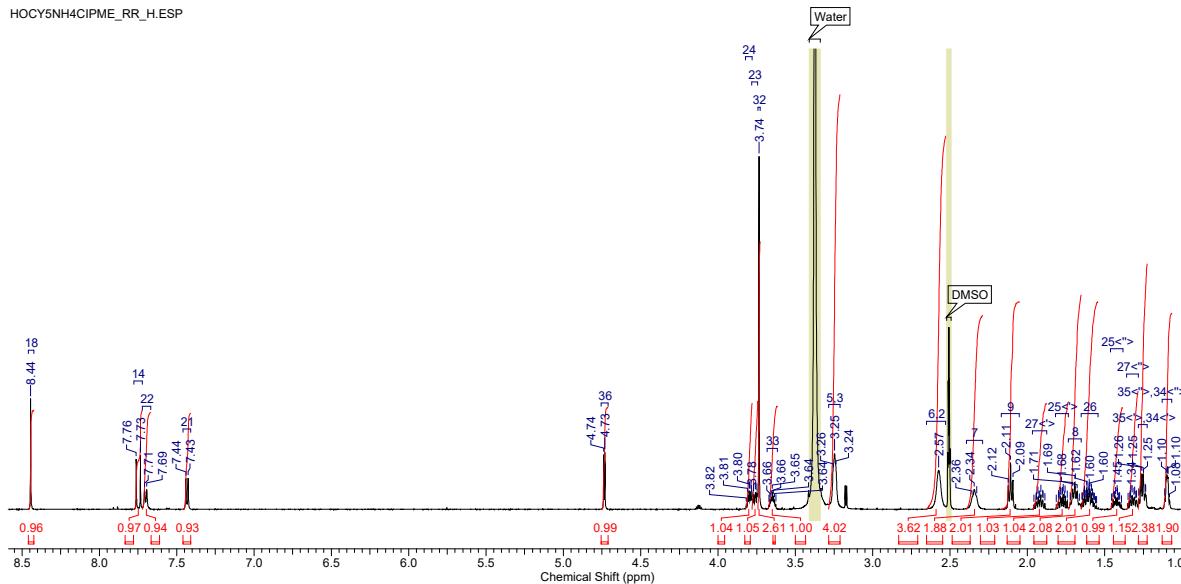
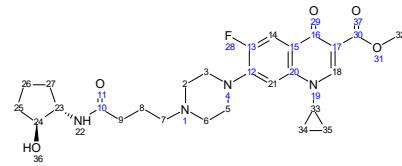
10.29 4-Azido-*N*-(*1R,2R*)-2-hydroxycyclopentyl)butanamide 124



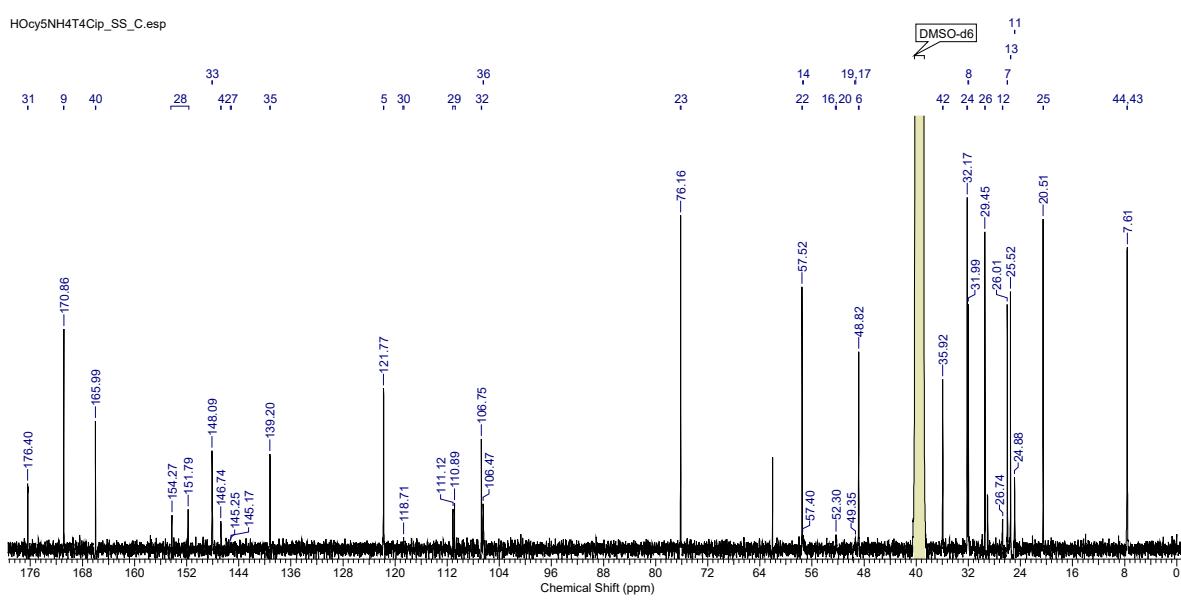
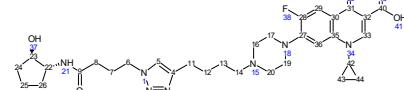
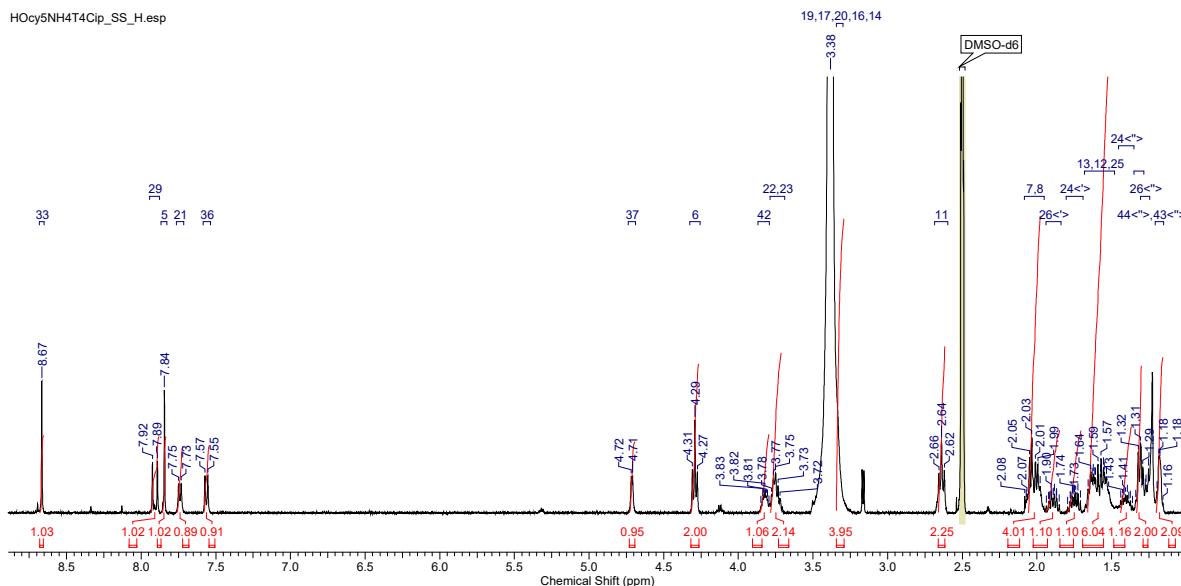
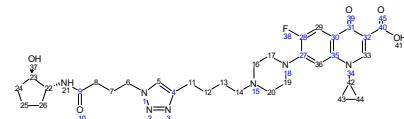
10.30 Methyl 1-cyclopropyl-6-fluoro-7-(4-((1*S*,2*S*)-2-hydroxycyclopentyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 125



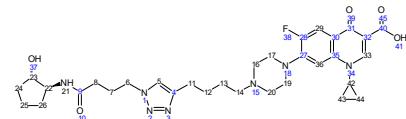
10.31 Methyl 1-cyclopropyl-6-fluoro-7-(4-(4-(((1*R*,2*R*)-2-hydroxycyclopentyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 126



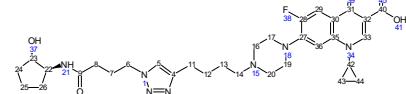
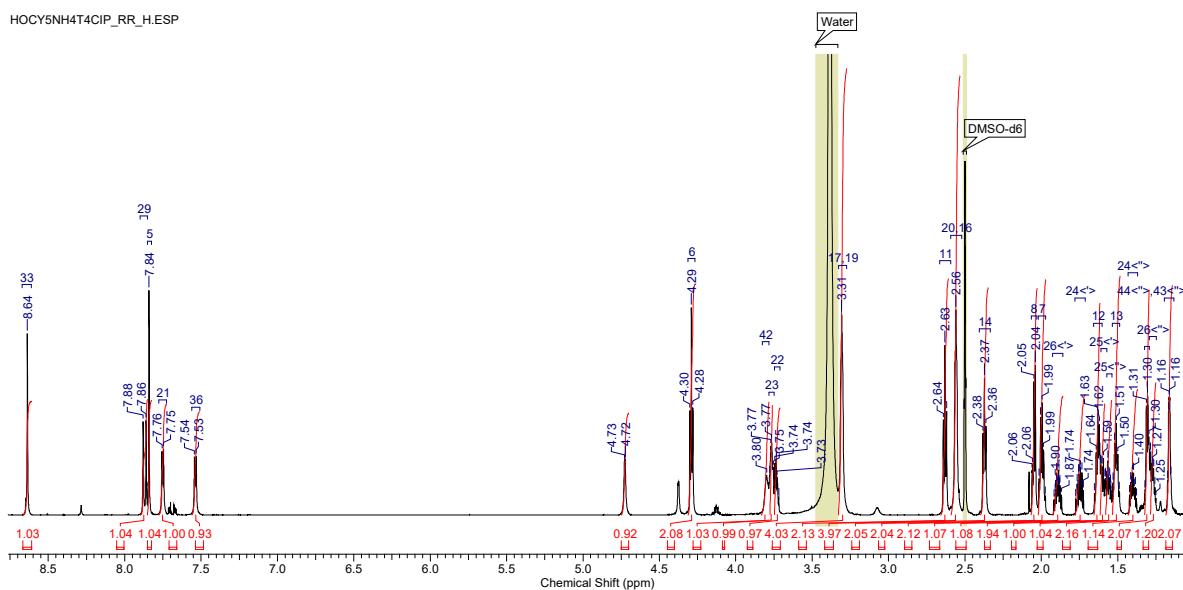
10.32 1-Cyclopropyl-6-fluoro-7-(4-(4-(1-(4-(((1*S*,2*S*)-2-hydroxycyclopentyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-4-oxo-1,4-dihydroquino-line-3-carboxylic acid 128



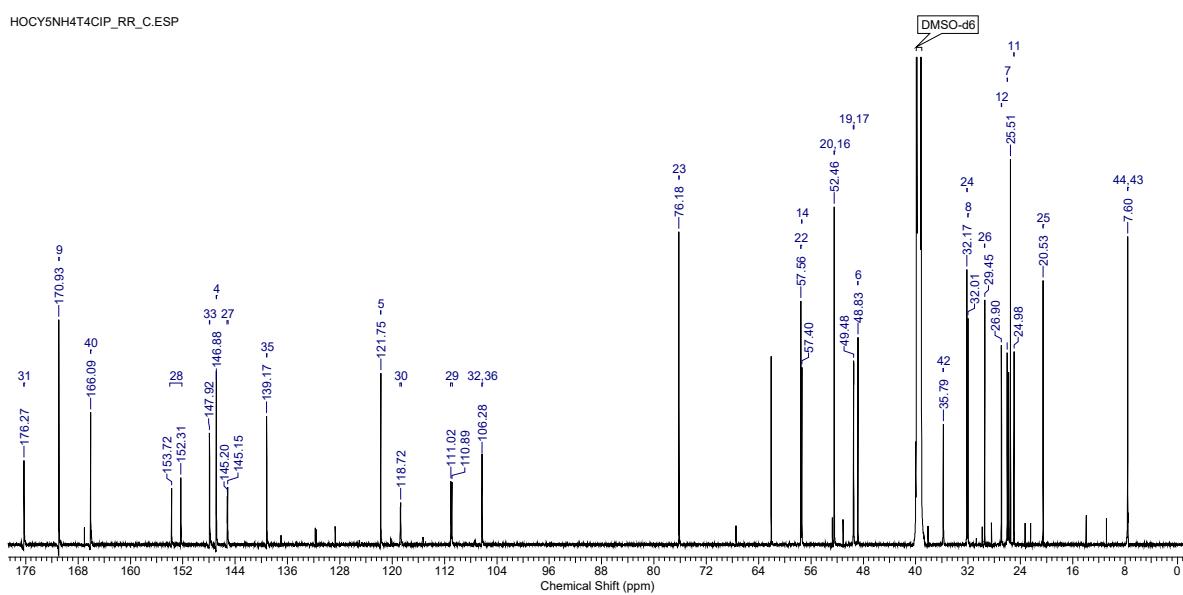
10.33 1-Cyclopropyl-6-fluoro-7-(4-(4-((1*R*,2*R*)-2-hydroxycyclopentyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-ylbutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 129



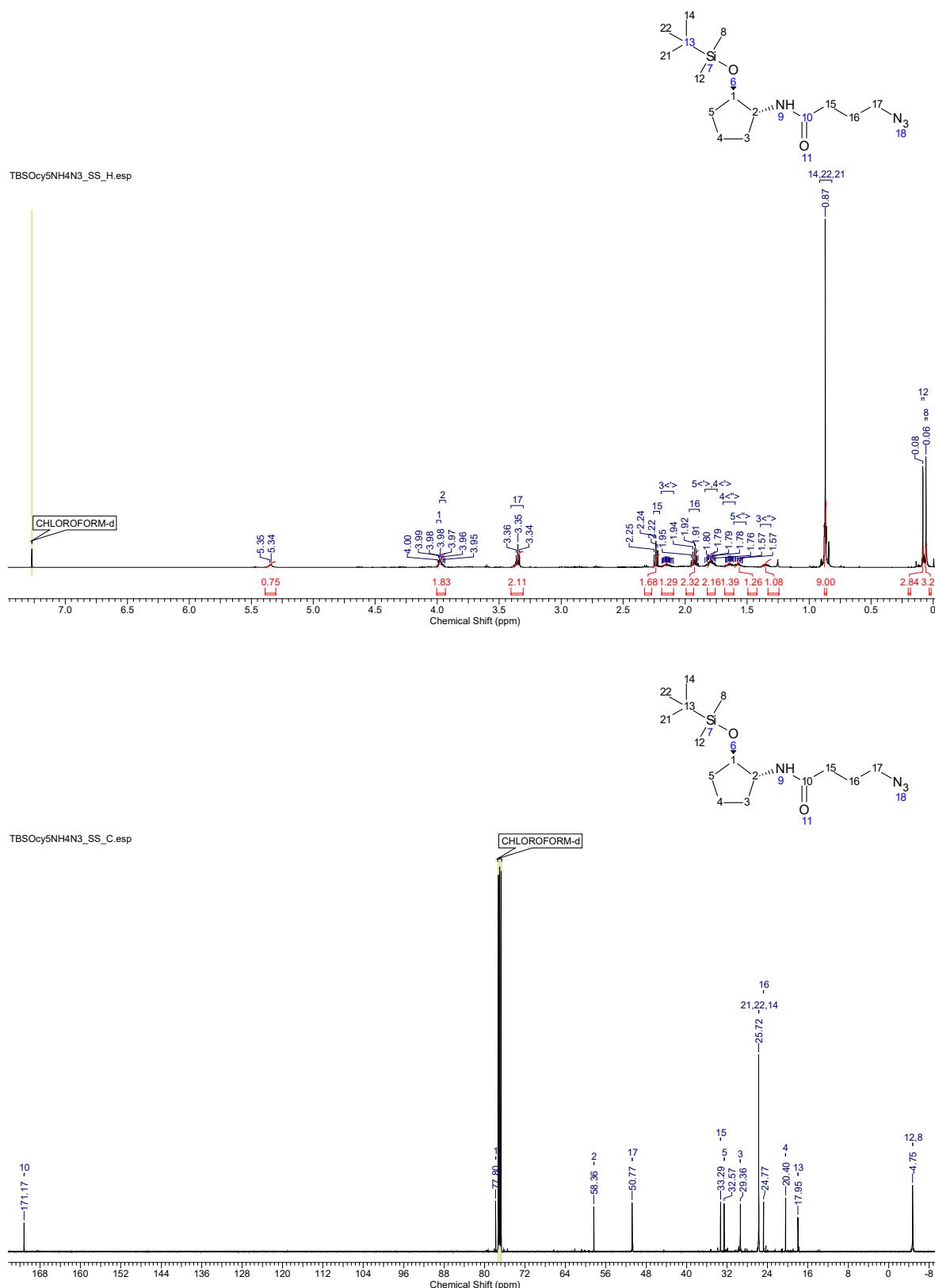
HOCY5NH4T4CIP_RR_H_ESP



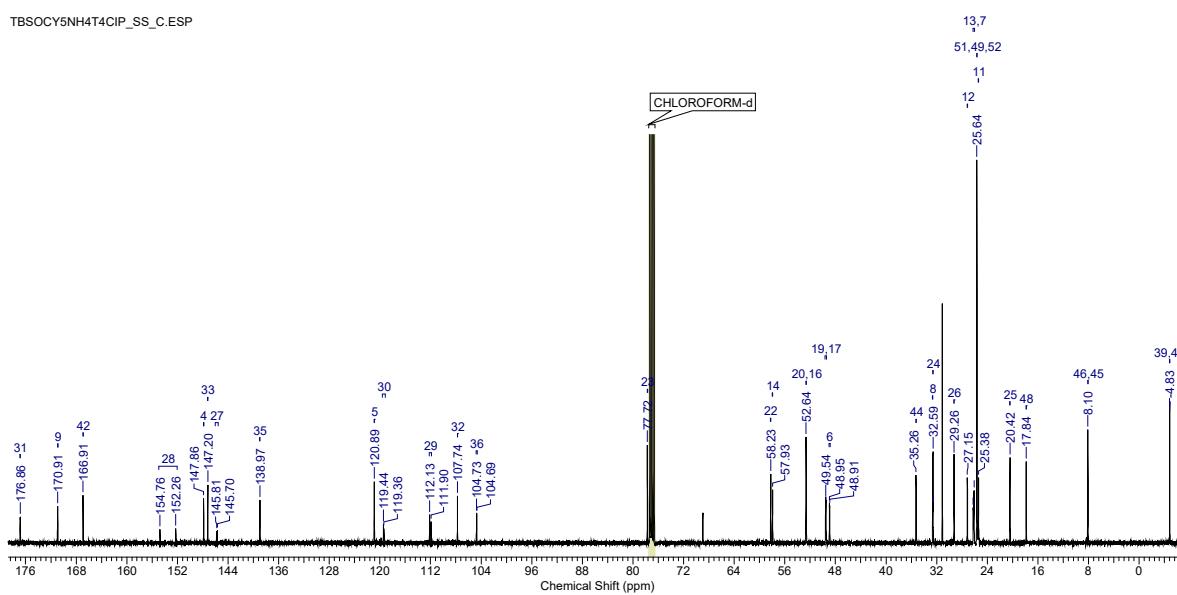
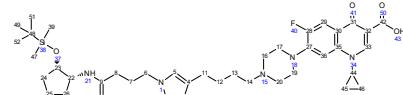
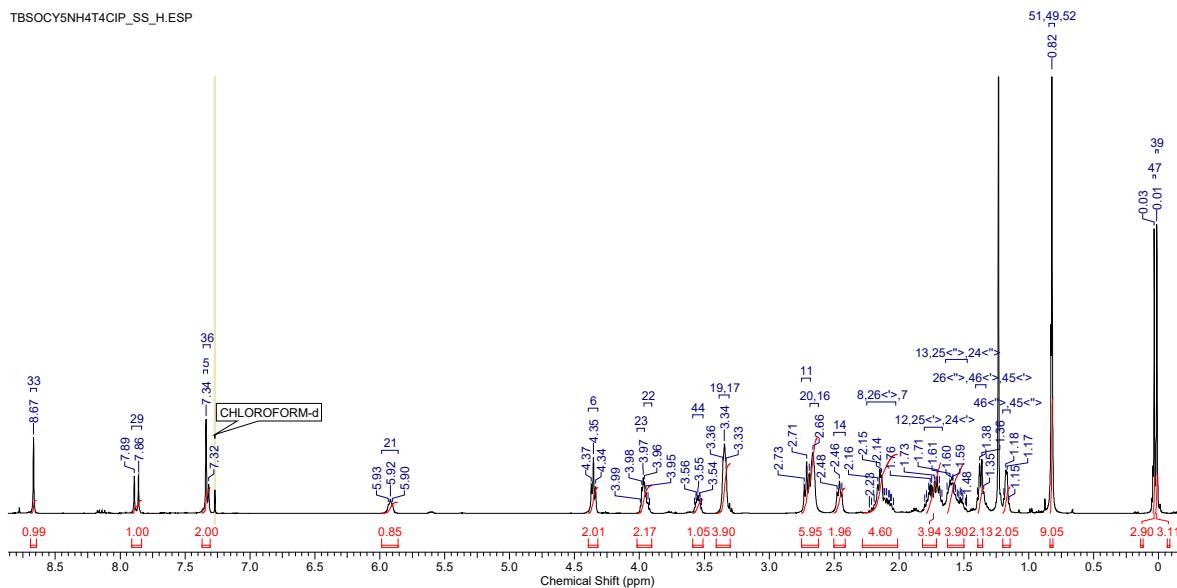
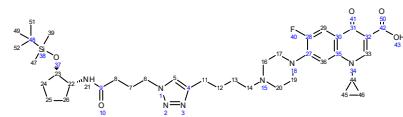
HOCY5NH4T4CIP_RR_C_ESP



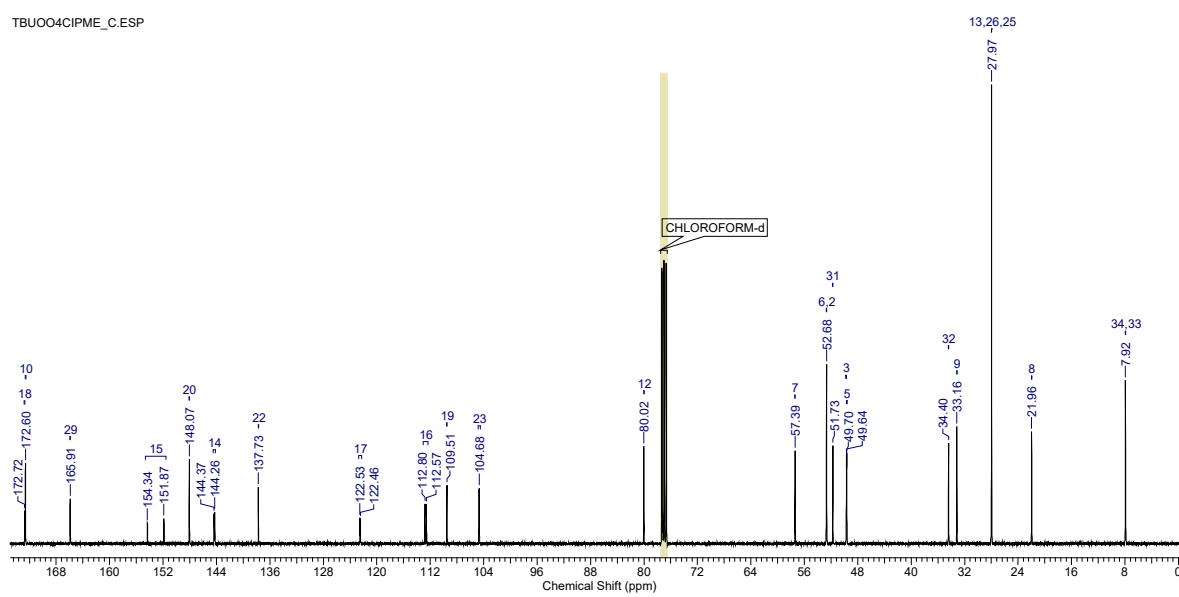
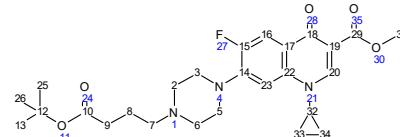
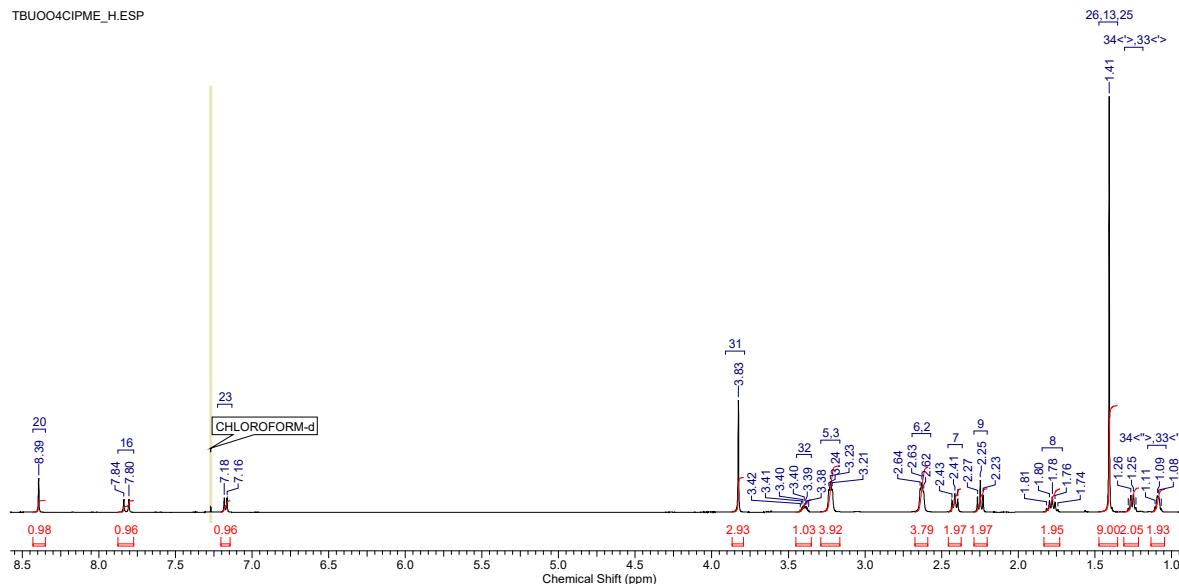
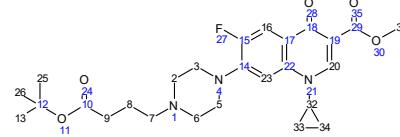
10.34 4-Azido-*N*-((1*S*,2*S*)-2-((*tert*-butyldimethylsilyl)oxy)cyclopentyl)butanamide
134



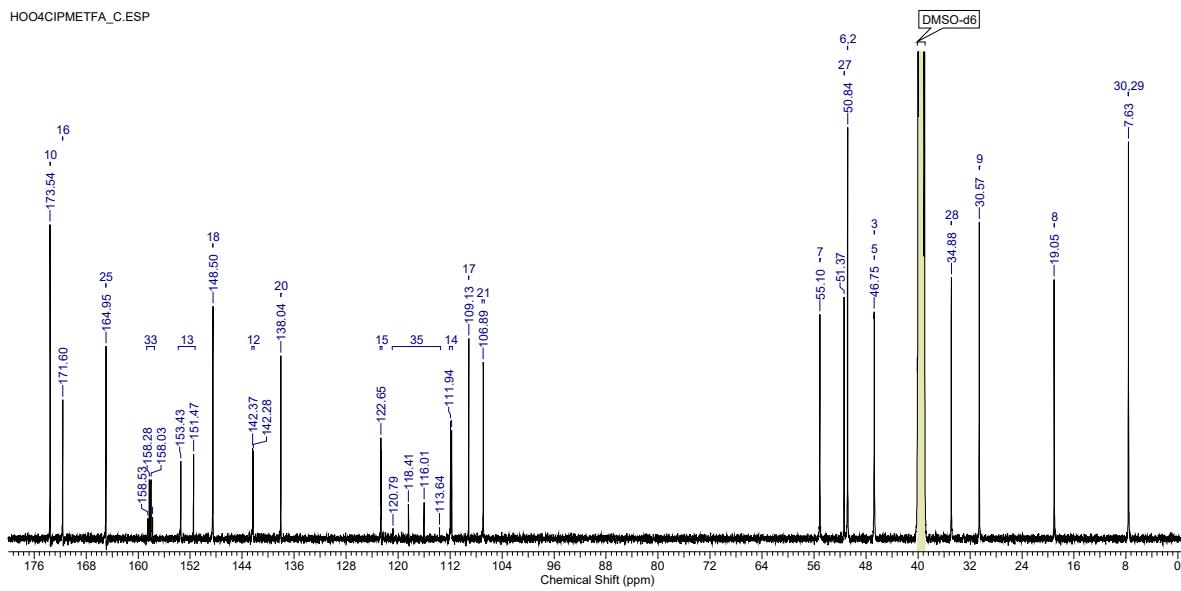
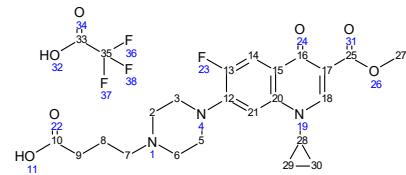
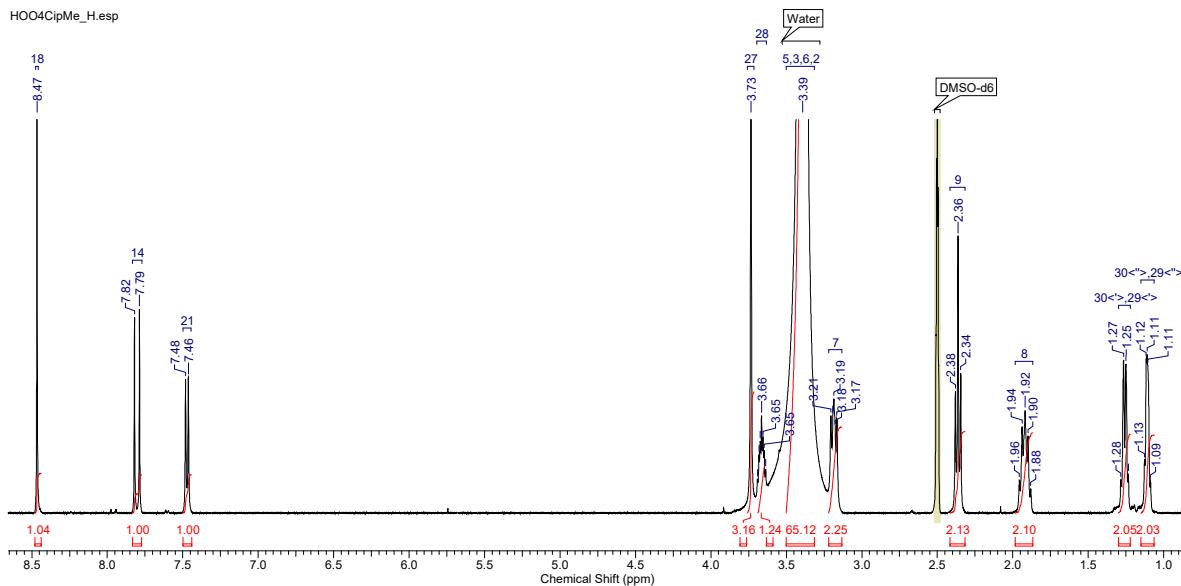
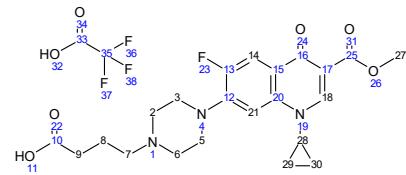
10.35 7-(4-(4-(1-(4-(((1*S*,2*S*)-2-((*tert*-butyldimethylsilyl)oxy)cyclopentyl)amino)-4-oxobutyl)-1*H*-1,2,3-triazol-4-yl)butyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylic acid 138



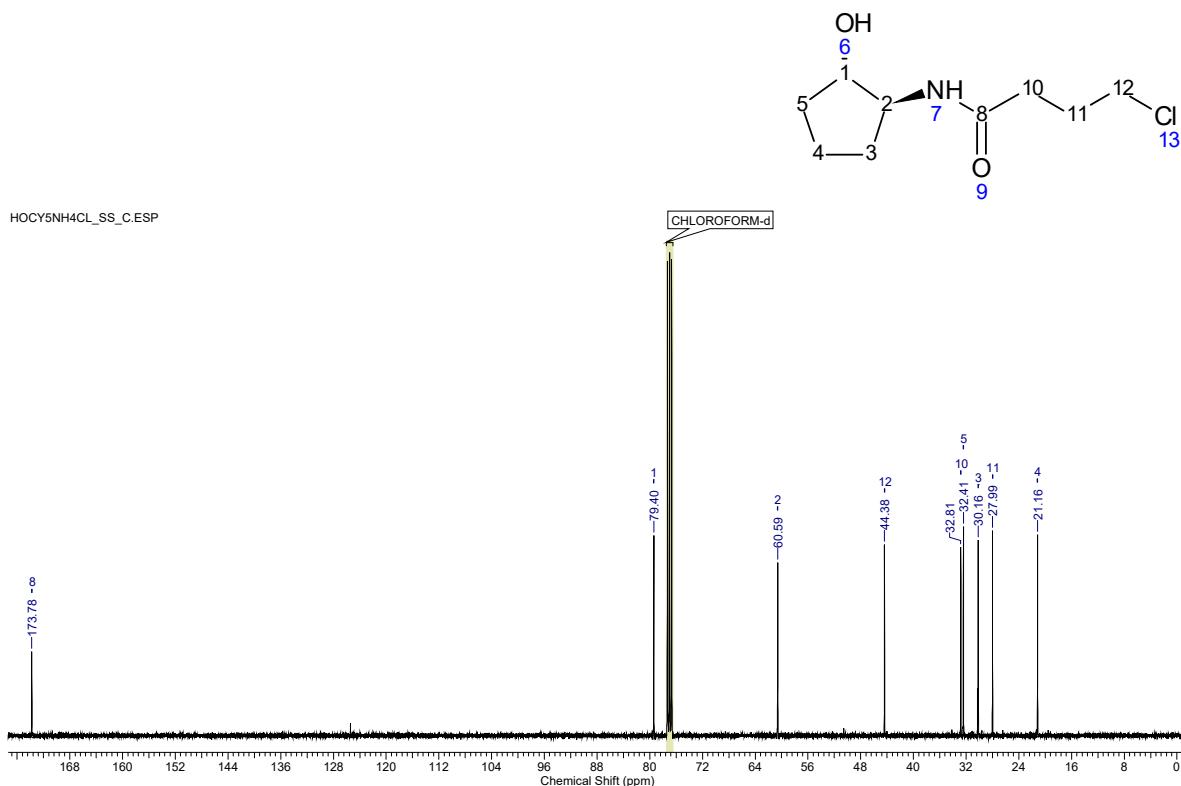
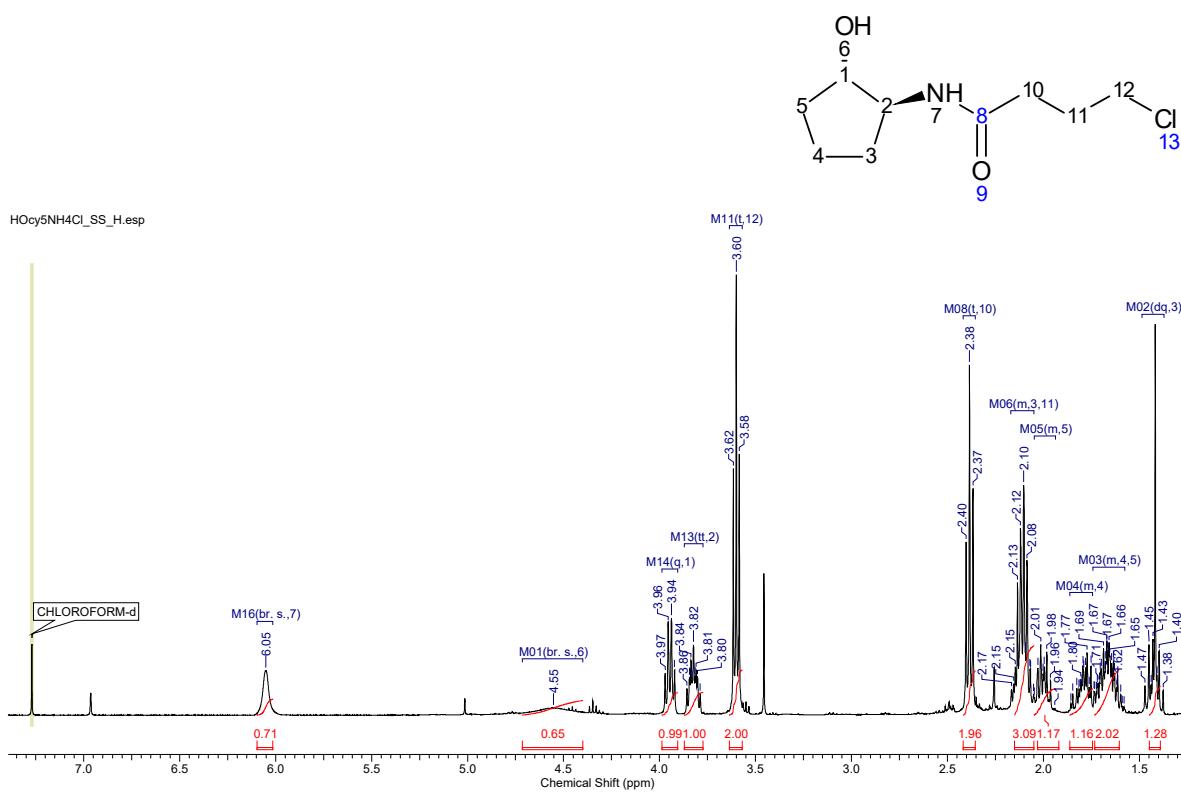
10.36 Methyl 7-(4-(*tert*-butoxy)-4-oxobutyl)piperazin-1-yl)-1-cyclopropyl-6-fluoro-4-oxo-1,4-dihydroquinoline-3-carboxylate 141



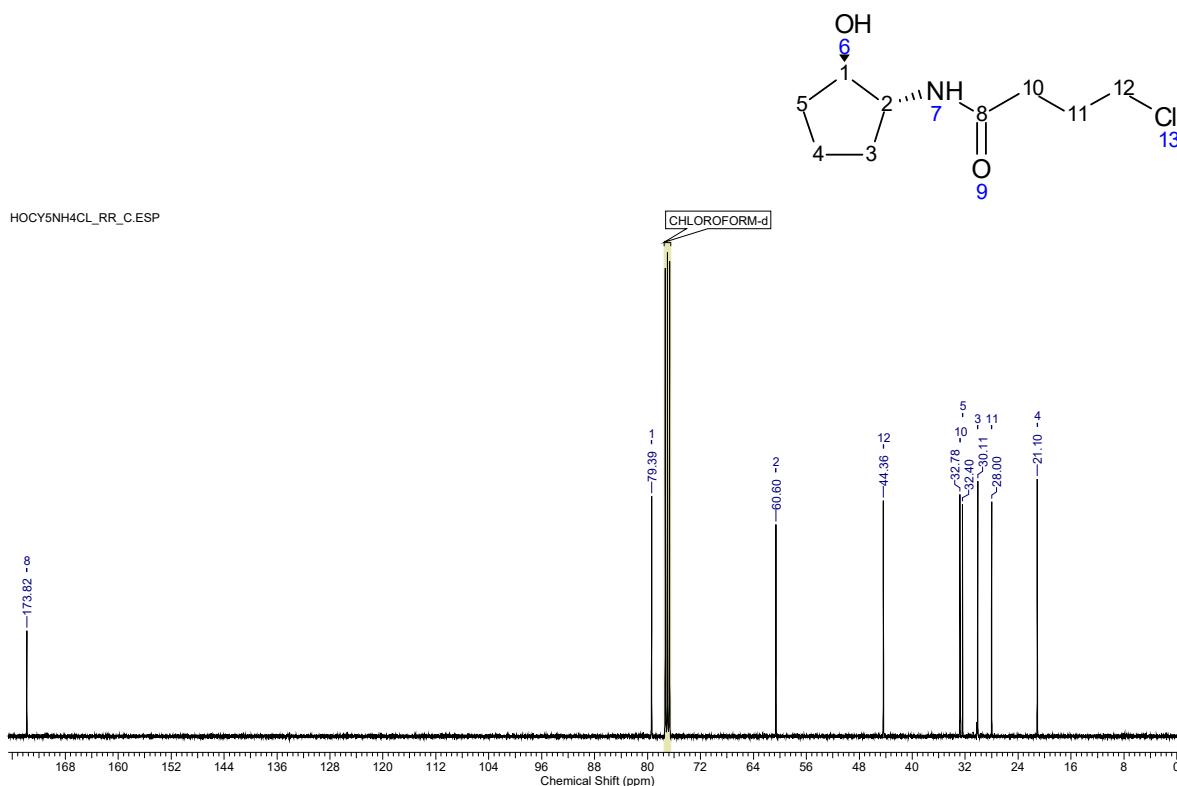
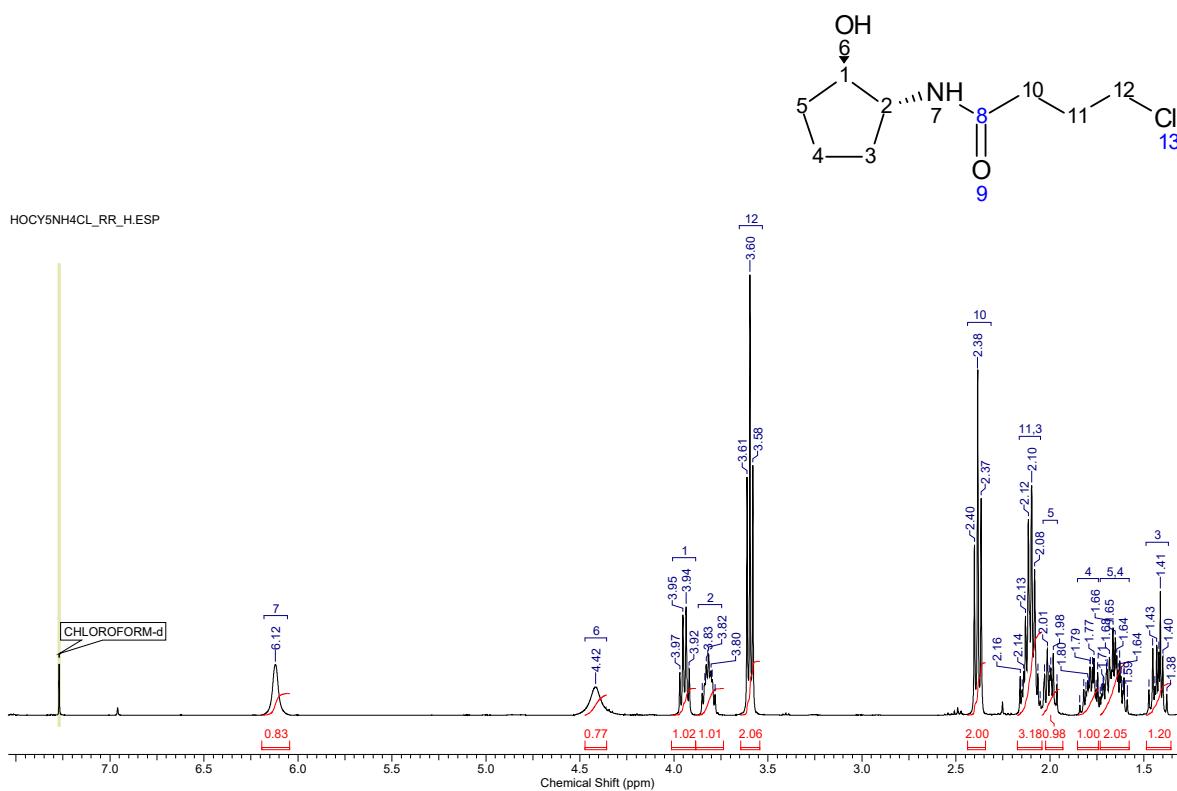
10.37 4-(4-(1-Cyclopropyl-6-fluoro-3-(methoxycarbonyl)-4-oxo-1,4-dihydroquinolin-7-yl)piperazin-1-yl)butanoic acid, trifluoroacetic acid salt 142



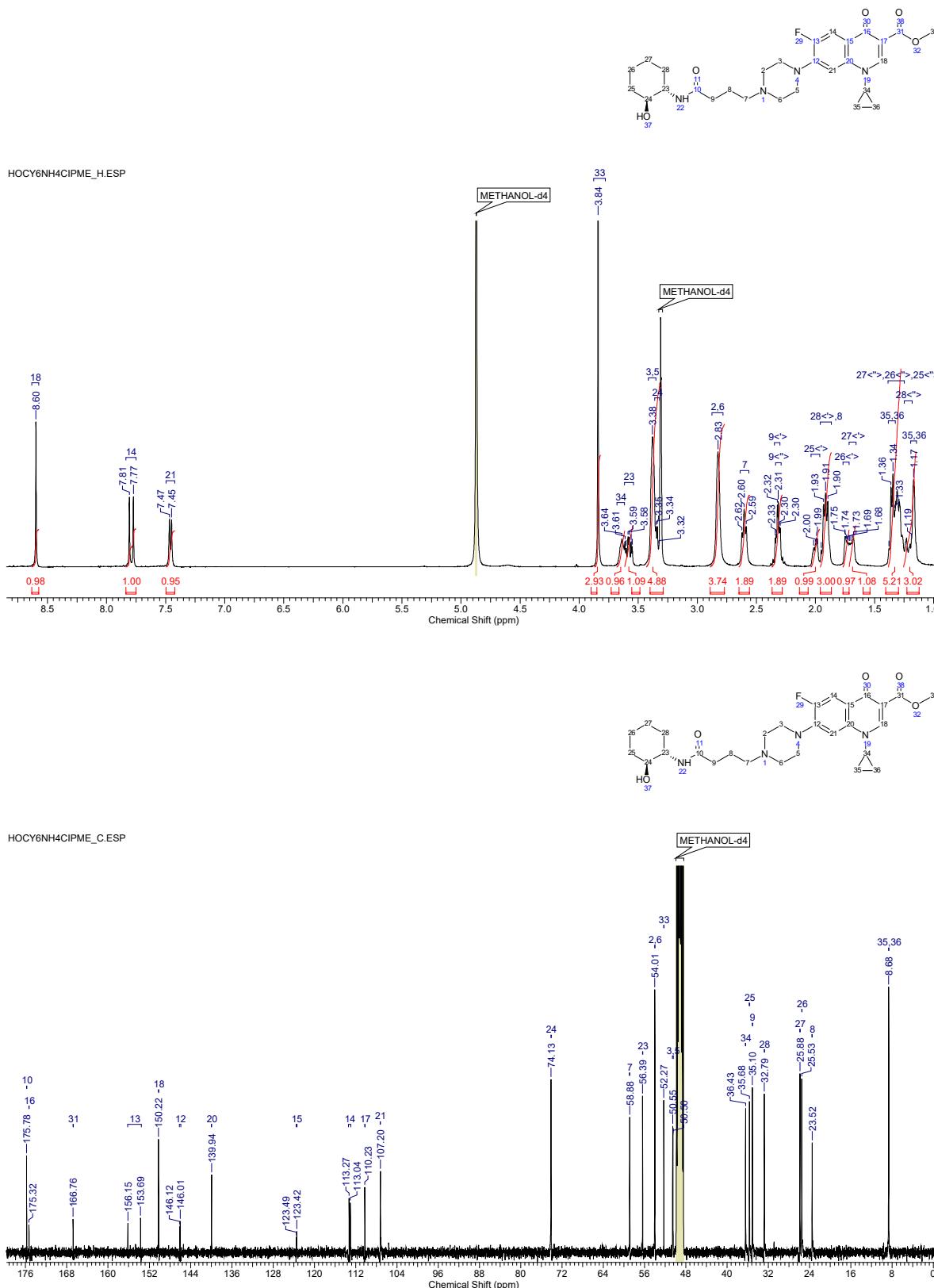
10.38 4-Chloro-*N*-(*1S,2S*)-2-hydroxycyclopentylbutanamide 144



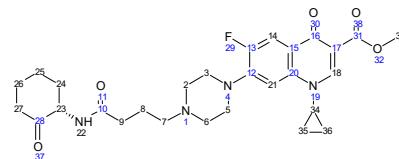
10.39 4-Chloro-*N*-(*1R,2R*)-2-hydroxycyclopentylbutanamide 145



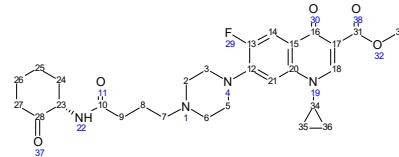
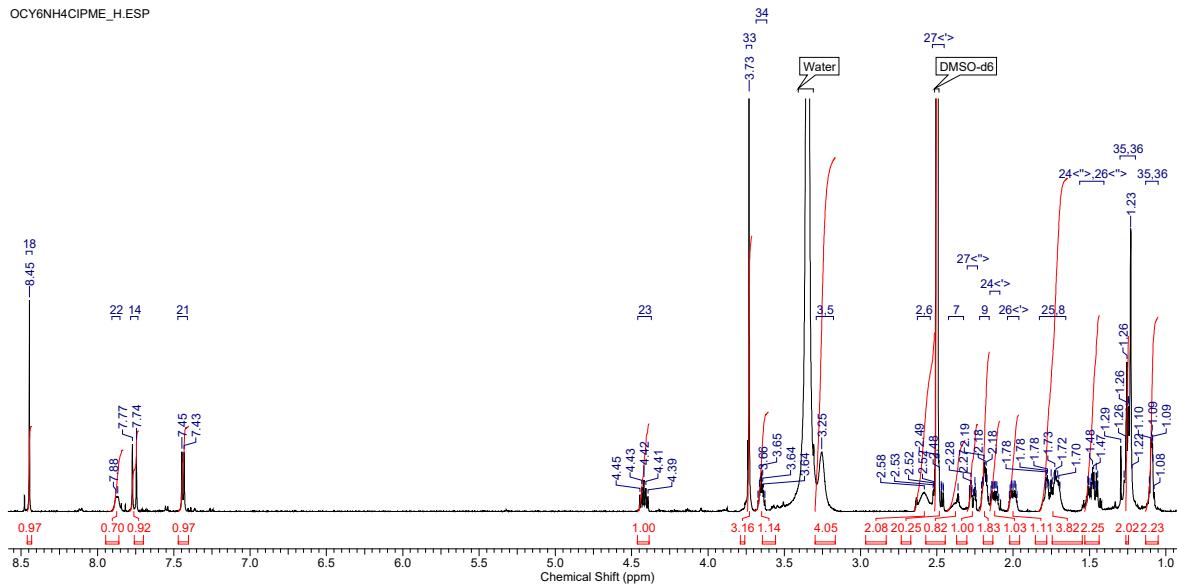
10.40 Methyl 1-cyclopropyl-6-fluoro-7-(4-((*trans*)-2-hydroxycyclohexyl)amino)-4-oxobutyl)piperazin-1-yl)-4-oxo-1,4-dihydroquinoline-3-carboxylate 148



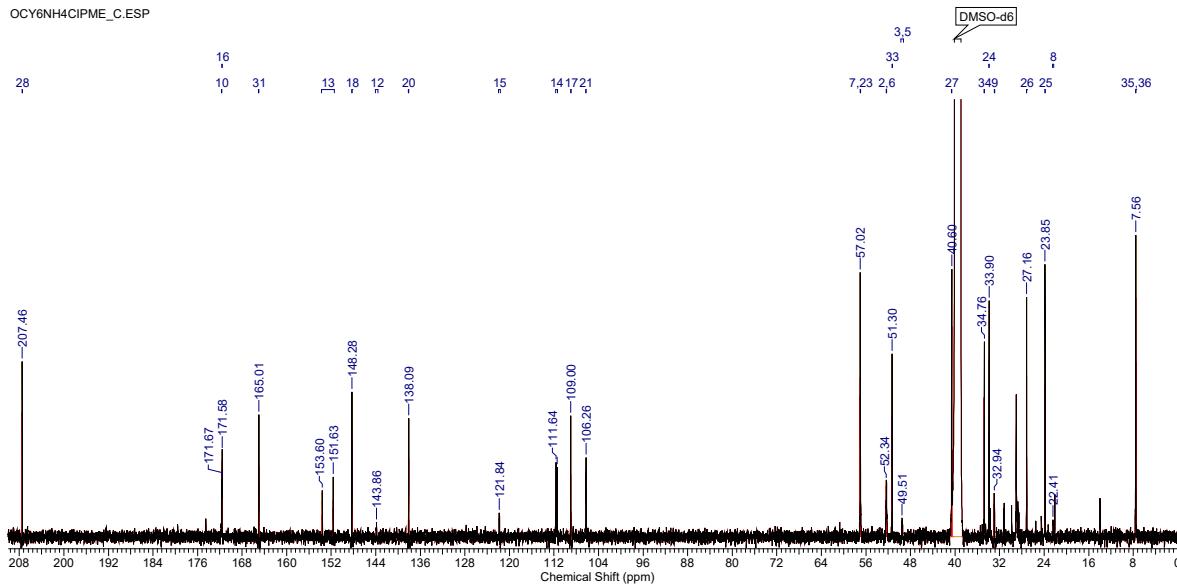
10.41 Methyl 1-cyclopropyl-6-fluoro-4-oxo-7-(4-(4-oxo-4-((2-oxocyclohexyl)amino)-butyl)piperazin-1-yl)-1,4-dihydroquinoline-3-carboxylate 149



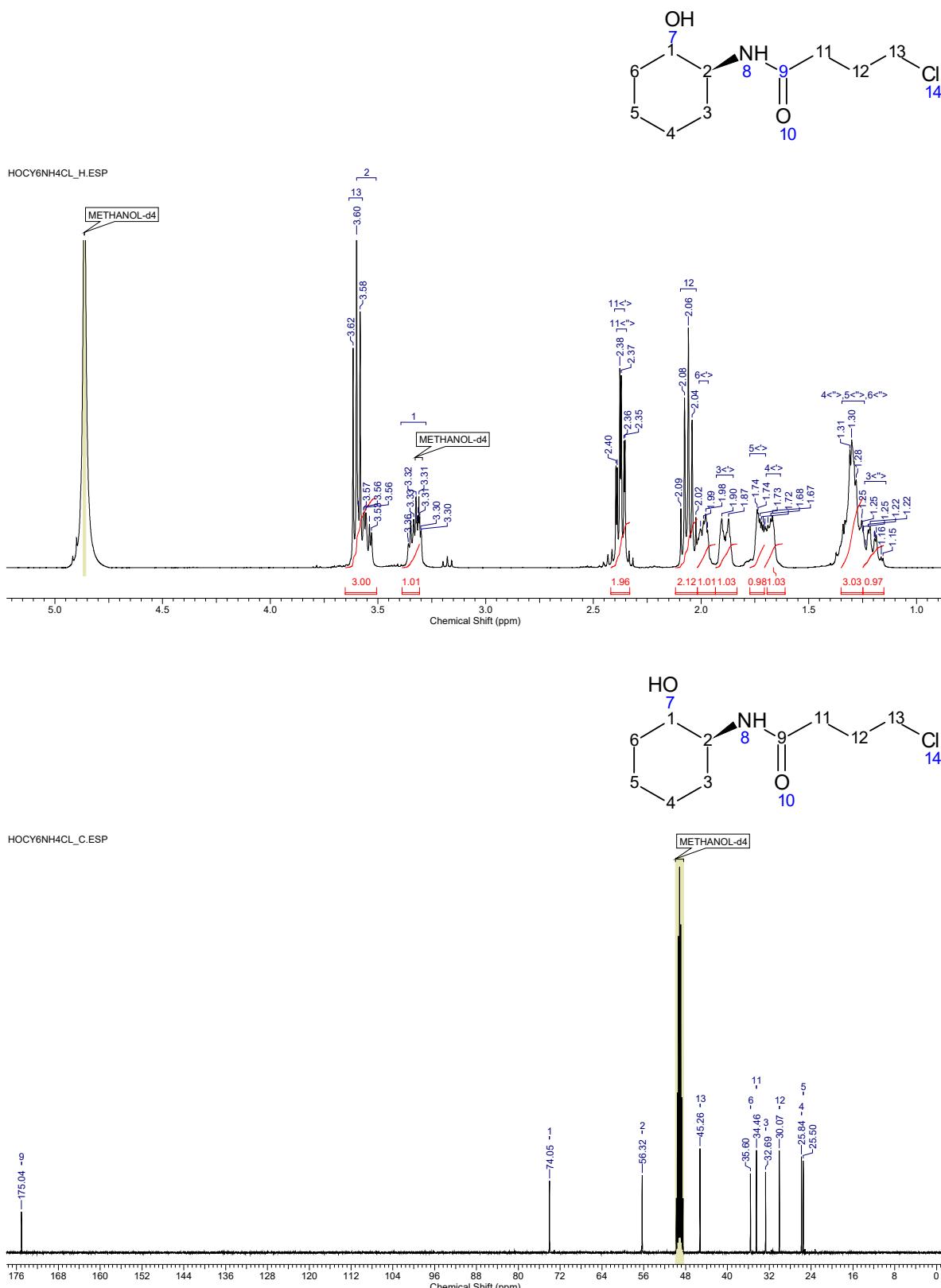
OCY6NH4CIPME_H.ESP



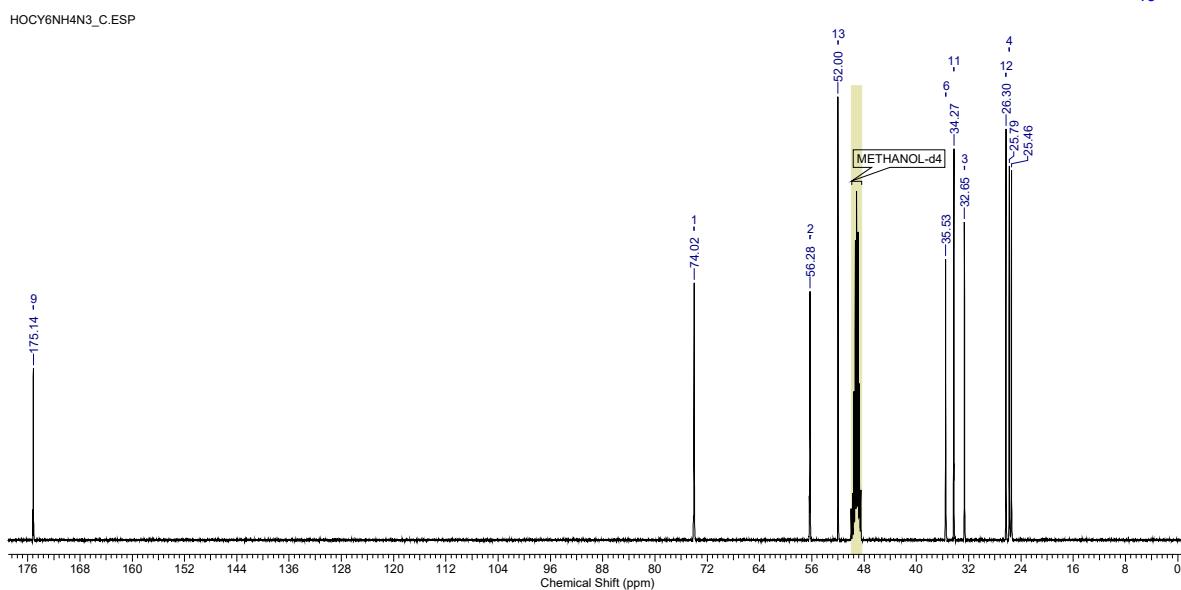
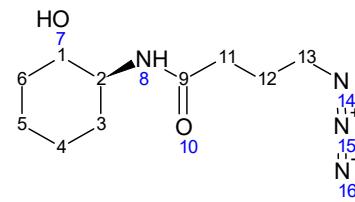
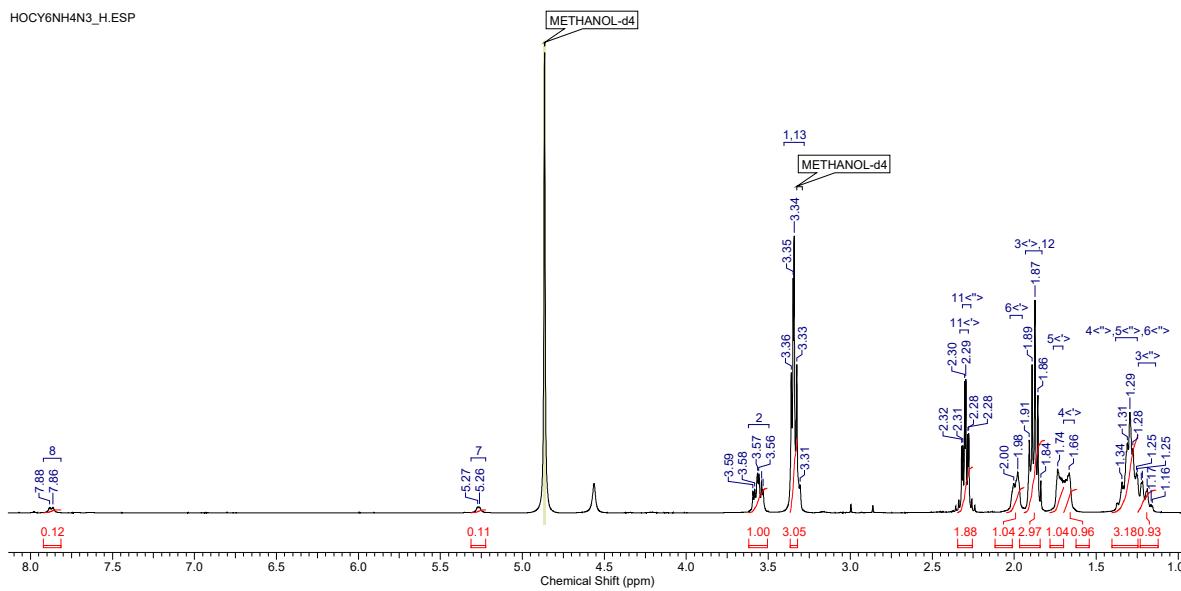
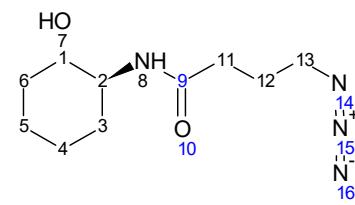
OCY6NH4CIPME_C.ESP



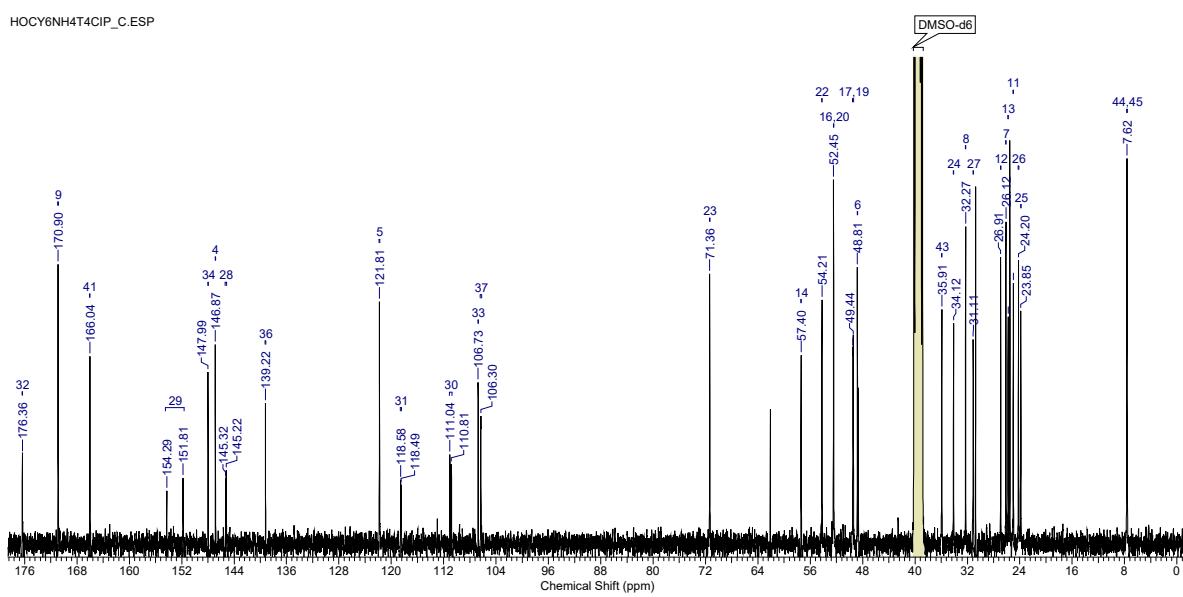
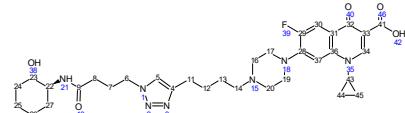
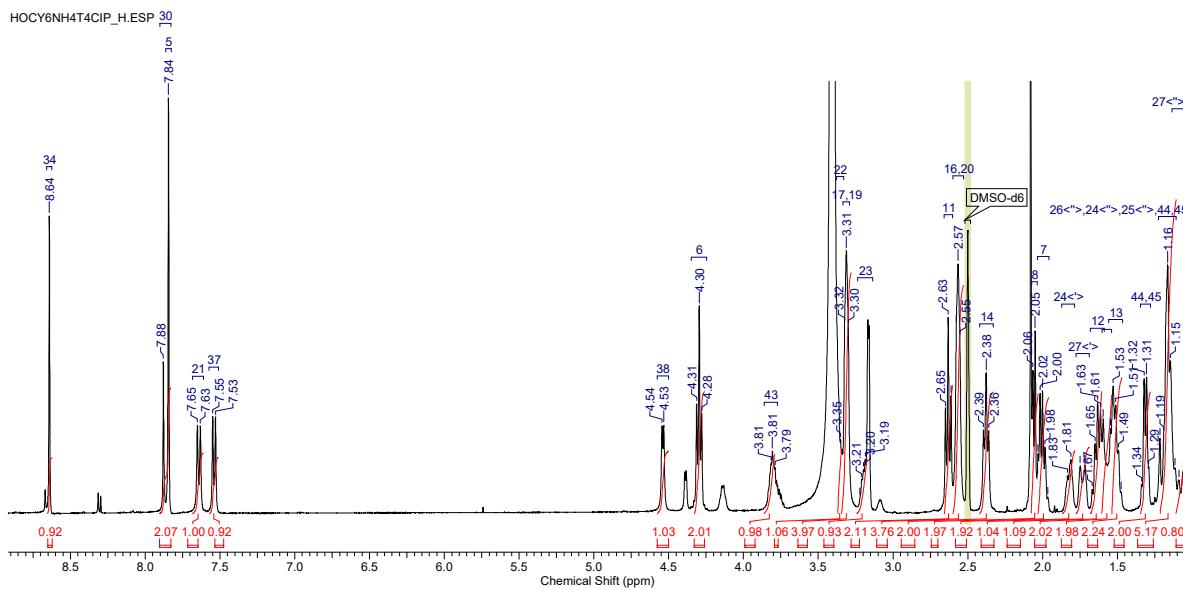
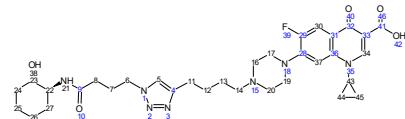
10.42 4-Chloro-*N*-(*trans*)-2-hydroxycyclohexyl)butanamide 150



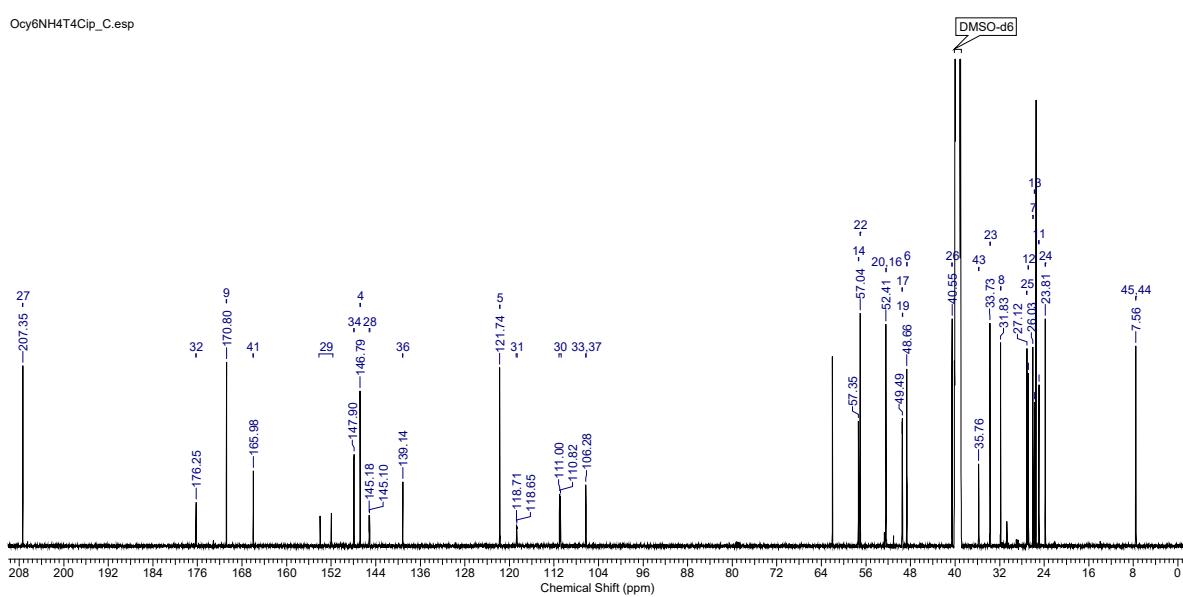
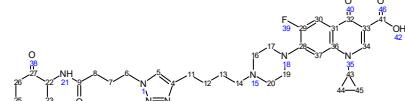
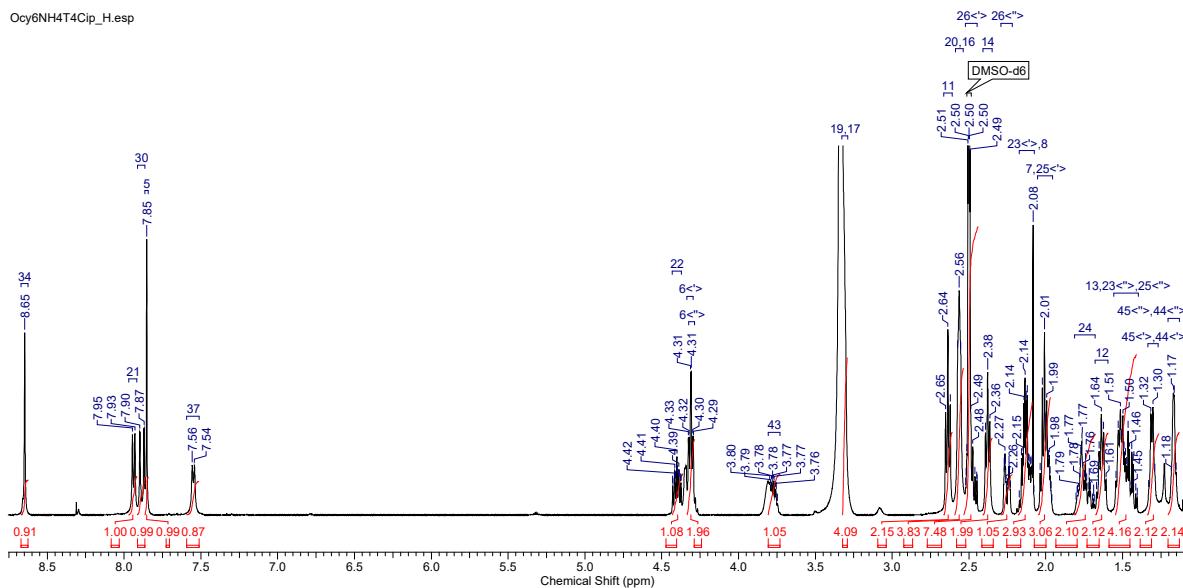
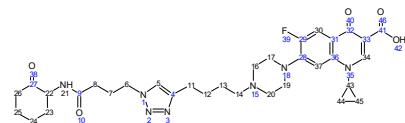
10.43 4-Azido-*N*-(*trans*)-2-hydroxycyclohexyl)butanamide 151



10.44 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 152



10.45 1-Cyclopropyl-6-fluoro-4-oxo-7-(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 153



yields
2dp

percent

11 References

- [1] *Antibiotic Resistance Threats in the United States*. 2013.
- [2] S. C. Davies, *The Drugs Don't Work: A Global Threat*, Penguin Books Limited. 2013.
- [3] K. M. G. O'Connell, J. T. Hodgkinson, H. F. Sore, M. Welch, P. George, C. Salmond, D. R. Spring and G. P. C. Salmond. Combating multidrug-resistant bacteria: current strategies for the discovery of novel antibacterials. *Angewandte Chemie International Edition*, 52(41):10706–10733. 2013.
- [4] M. G. P. Page. Siderophore conjugates. *Annals of the New York Academy of Sciences*, 1277:115–126. 2013.
- [5] I. J. Schalk and G. L. A. Mislin. Bacterial Iron Uptake Pathways: Gates for the Import of Bactericide Compounds. 2017.
- [6] 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.
- [7] M. B. Miller and B. L. Bassler. Quorum sensing in bacteria. *Annual Review of Microbiology*, 55:165–199. 2001.
- [8] 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.
- [9] 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.
- [10] G. P. Bodey, R. Bolivar, V. Fainstein and L. Jadeja. Infections caused by *Pseudomonas aeruginosa*. *Reviews of Infectious Diseases*, 5(2):279–313. 1983.
- [11] K. Poole. Efflux-mediated multiresistance in Gram-negative bacteria. *Clinical Microbiology and Infection*, 10(1):12–26. 2004.
- [12] 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.
- [13] 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.
- [14] H.-C. Su, K. Ramkissoon, J. Doolittle, M. Clark, J. Khatun, A. Secrest, M. C. Wolfgang and M. C. Giddings. The development of ciprofloxacin resistance in *Pseudomonas aeruginosa* involves multiple response stages and multiple proteins. *Antimicrobial Agents and Chemotherapy*, 54(11):4626–4635. 2010.
- [15] 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.
- [16] M. Barber. Staphylococcal infection due to penicillin-resistant strains. *British Medical Journal*, 2(4534):863–865. 1947.
- [17] 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.

- [18] P. S. Stewart and J. W. Costerton. Antibiotic resistance of bacteria in biofilms. *The Lancet*, 358(9276):135–138. 2001.
- [19] 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.
- [20] O. Sköld. Sulfonamide resistance: mechanisms and trends. *Drug Resistance Updates*, 3(3):155–160. 2000.
- [21] 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.
- [22] S. R. Palumbi. Humans as the World’s Greatest Evolutionary Force. *Science*, 293(5536):1786–1790. 2001.
- [23] 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.
- [24] P. Huovinen. Resistance to Trimethoprim-Sulfamethoxazole. *Antimicrobial Resistance*, 32(11):1608–1614. 2001.
- [25] 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.
- [26] 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.
- [27] H. W. Boucher, G. H. Talbot, J. S. Bradley, J. E. Edwards, D. Gilbert, L. B. Rice, M. Scheld, B. Spellberg and J. Bartlett, *Bad Bugs , No Drugs : No ESKEAPE ! An Update from the Infectious Diseases Society of America*. 2009.
- [28] S. Harbarth, G. Kahlmeter, J. Kluytmans, M. Mendelson, G. S. Hospital, C. Town, S. Africa, C. Pulcini, N. Singh, U. Theuretzbacher, C. U. S. Food, S. Spring, L. Grayson, C. Houchens, D. L. Monnet, M. Ouellette, J. B. Patel, N. Zealand, E. Carrara, A. Savoldi, D. Kattula and F. Burkert. GLOBAL PRIORITY LIST OF ANTIBIOTIC-RESISTANT BACTERIA TO GUIDE RESEARCH , DISCOVERY , AND DEVELOPMENT OF .
- [29] W. E. Forum, *Global Risks 2013 Eighth Edition*. 2013.
- [30] B. Spellberg, J. G. Bartlett and D. N. Gilbert. The Future of Antibiotics and Resistance. *The New England Journal of Medicine*, pages 299–302. 2013.
- [31] L. Lin, B. Tan, P. Pantapalangkoor, T. Ho, B. Baquir, A. Tomaras, J. I. Montgomery, E. G. Barbacci, K. Hujer, R. A. Bonomo, L. Fernandez, R. E. W. Hancock, M. D. Adams, S. W. French, V. S. Buslon and B. Spellberg. Inhibition of LpxC Protects Mice from Resistant *Acinetobacter baumannii* by Modulating Inflammation and Enhancing Phagocytosis. *mBio*, 3(5):23–29. 2012.
- [32] J. M. Lambert and A. Berkenblit. Antibody – Drug Conjugates for Cancer Treatment. 2018.
- [33] R. C. Hider and X. L. Kong. Chemistry and biology of siderophores. *Natural Product Reports*, 27(5):637–657. 2010.

- [34] 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.
- [35] T. Zheng and E. M. Nolan. Siderophore-based detection of Fe(III) and microbial pathogens. *Metallomics*, 4(9):866–880. 2012.
- [36] 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.
- [37] 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*, $\text{FeC}_3\text{H}_5\text{N}_6\text{O}_1\text{O}_1$. *Journal of the American Chemical Society*, 102(18):5766–5773. 1980.
- [38] 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.
- [39] J.-m. Meyer. Pyoverdines: pigments, siderophores and potential taxonomic markers of fluorescent *Pseudomonas* species. *Archives of Microbiology*, 174:135–142. 2000.
- [40] 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.
- [41] D. Cobessi, H. Celia and F. Pattus. Crystal Structure at High Resolution of Ferric-pyochelin and its Membrane Receptor FptA from *Pseudomonas aeruginosa*. pages 893–904. 2005.
- [42] 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.
- [43] 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.
- [44] G. F. Gause. Recent studies on albomycin, a new antibiotic. *British Medical Journal*, 2(4949):1177–1179. 1955.
- [45] 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.
- [46] 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.
- [47] 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.
- [48] V. Braun, A. Pramanik, T. Gwinner, M. Köberle and E. Bohn. Sideromycins: tools and antibiotics. *Biometals*, 22:3–13. 2009.
- [49] W. Sackmann, P. Reusser, L. Neipp, F. Kradolfer and F. Gross. Ferrimycin A, a new iron-containing antibiotic. *Antibiotics & Chemotherapy*, 12:34–45. 1962.
- [50] D. Gottlieb and P. D. Shaw, *Mechanism of Action*, Springer. 2012.

- [51] G. Benz, T. Schröder, J. Kurz, C. Wünsche, W. Karl, G. Steffens, J. Pfitzner and D. Schmidt. Constitution of the deferriform of the albolomycins $\delta 1$, $\delta 2$ and ϵ . *Angewandte Chemie International Edition in English*, 21(7):527–528. 1982.
- [52] 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.
- [53] C. Dini and J. Aszodi. Synthesis of a dihydroxythiophene analogue of catechosporines. *Bioorganic & Medicinal Chemistry Letters*, 10(4):349–352. 2000.
- [54] 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.
- [55] Y. Lu and M. J. Miller. Syntheses and Studies of Multiwarhead Siderophore-5-fluorouridine Conjugates. *Bioorganic & Medicinal Chemistry*, 7(1999):3025–3038. 1999.
- [56] 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.
- [57] 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.
- [58] 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.
- [59] 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.
- [60] 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.
- [61] 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.
- [62] 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.
- [63] J. M. Harrington, T. Gootz, M. Flanagan, M. Lall, J. O'Donnell, J. Winton, J. Mueller and A. L. Crumbly. 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.
- [64] 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.

- [65] 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.
- [66] 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.
- [67] 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.
- [68] 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.
- [69] *Oxford English Dictionary*, Oxford University Press. 2014.
- [70] 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.
- [71] S. Atkinson, C.-Y. Chang, R. E. Sockett, M. Câmara and P. Williams. Quorum Sensing in *Yersinia enterocolitica* Controls Swimming and Swarming Motility. *Journal of Bacteriology*, 188(4):1451–1461. 2006.
- [72] 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.
- [73] 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.
- [74] 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.
- [75] B. M. M. Ahmer. Cell-to-cell signalling in *Escherichia coli* and *Salmonella enterica*. *Molecular Microbiology*, 52(4):933–945. 2004.
- [76] 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.
- [77] 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.
- [78] 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.
- [79] 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.
- [80] 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.

- [81] 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.
- [82] 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.
- [83] 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.
- [84] 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.
- [85] 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.
- [86] 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.
- [87] 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.
- [88] 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.
- [89] 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.
- [90] J. Engebrecht, K. Nealson and M. Silverman. Bacterial bioluminescence: isolation and genetic analysis of functions from *Vibrio fischeri*. *Cell*, 32(3):773–781. 1983.
- [91] 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.
- [92] 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.
- [93] 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.
- [94] 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.
- [95] P. Cornelis, *Pseudomonas: Genomics and Molecular Biology*, Caister Academic Press. 2008.
- [96] H. Nikaido. Outer Membrane Barrier as a Mechanism of Antimicrobial Resistance. 33(11):1831–1836. 1989.

- [97] 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.
- [98] 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.
- [99] 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.
- [100] 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.
- [101] 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.
- [102] 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.
- [103] 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.
- [104] 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.
- [105] 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.
- [106] 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 RhlR (VsmR) to expression of the stationary-phase sigma factor RpoS. *Molecular Microbiology*, 21(6):1137–1146. 1996.
- [107] 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.
- [108] 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.
- [109] J. M. Brint and D. E. Ohman. Synthesis of multiple exoproducts in *Pseudomonas aeruginosa* is under the control of RhlR-RhlI, another set of regulators in strain PAO1 with homology to the autoinducer-responsive LuxR-LuxI family. *Journal of Bacteriology*, 177(24):7155–7163. 1995.
- [110] 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.

- [111] 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.
- [112] 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.
- [113] 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.
- [114] 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.
- [115] 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.
- [116] 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.
- [117] 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.
- [118] 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.
- [119] 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.
- [120] 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.
- [121] 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.
- [122] 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.
- [123] 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.
- [124] 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.

- [125] 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. Cámaras 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.
- [126] 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.
- [127] C. S. Pereira, J. A. Thompson and K. B. Xavier. AI-2-mediated signalling in bacteria. *FEMS Microbiology Reviews*, 37(2):156–181. 2013.
- [128] 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.
- [129] 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.
- [130] 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.
- [131] 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.
- [132] 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.
- [133] 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.
- [134] 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.
- [135] C. M. Oliphant and G. M. Green. Quinolones: a comprehensive review. *American Family Physician*, 65(3):455–464. 2002.
- [136] K. Drlica and X. Zhao. DNA Gyrase , Topoisomerase IV , and the 4-Quinolones. 61(3):377–392. 1997.
- [137] 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.
- [138] R. A. Celesk and N. J. Robillard. Factors Influencing the Accumulation of Ciprofloxacin in *Pseudomonas aeruginosa*. 33(11):1921–1926. 1989.
- [139] K. Poole. MINIREVIEW Efflux-Mediated Resistance to Fluoroquinolones in Gram-Negative Bacteria. 44(9):2233–2241. 2000.

- [140] 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.
- [141] 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.
- [142] 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.
- [143] 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.
- [144] 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.
- [145] 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.
- [146] R. Iyer, K. Ganguly and L. A. Silks. Synthetic analogs of bacterial quorum sensors. Los Alamos National Laboratory. 2012.
- [147] 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.
- [148] 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.
- [149] 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.
- [150] 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.
- [151] 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.
- [152] 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.
- [153] 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.

- [154] 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.
- [155] 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.
- [156] 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.
- [157] G. J. Jog, J. Igarashi and H. Suga. Stereoisomers of *P. aeruginosa* Autoinducer Analog to Probe the Regulator Binding Site. *Chemistry and Biology*. 2006.
- [158] 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.
- [159] 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.
- [160] 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.
- [161] Y. R. Baker. Investigating quinolone based quorum sensing in *Pseudomonas aeruginosa* using a chemical proteomics approach. PhD thesis, University of Cambridge. 2015.
- [162] 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.
- [163] 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.
- [164] 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.
- [165] Y. R. Baker. Novel Affinity Based Probes for Use in Chemical Proteomic Studies. CPGS thesis. University of Cambridge. 2012.
- [166] 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.
- [167] 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.
- [168] 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.

- [169] 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.
- [170] 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.
- [171] 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.
- [172] D. K. Yung, L. G. Chatten and D. P. MacLeod. 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.
- [173] 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.
- [174] 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.
- [175] 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.
- [176] 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.
- [177] K. Sachin, E.-M. Kim, S.-J. Cheong, H.-J. Jeong, S. T. Lim, M.-H. Sohn and D. W. Kim. Synthesis of N₄'-[¹⁸F]fluoroalkylated ciprofloxacin as a potential bacterial infection imaging agent for PET study. *Bioconjugate Chemistry*, 21(12):2282–2288. 2010.
- [178] Y. O. Mezhuev, Y. V. Korshak and M. I. Shtilman. Oxidative polymerization of aromatic amines: kinetic features and possible mechanisms. 2017.
- [179] 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.
- [180] 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.
- [181] 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.
- [182] 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.

- [183] 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.
- [184] 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.
- [185] 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.
- [186] 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.
- [187] 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.
- [188] 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.
- [189] 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.
- [190] 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.
- [191] 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.
- [192] 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

analogues,cleavables, bio	9
pre-release paper	20
better quality diagrams	23
add numbers manually when sorted	25
Boursier2018 pre-release, check for updates	30
weigh Y4Tri then discuss	38
ref	41
link this up	45
link this up	46
cleavables intro	46
sort numbering	62
????	74
don't have?	77
don't have?	77
try?	77

works in LCMS see Lois283	96
remove unless very active as not fully characterised	114
yields 2dp	174
percent no space	174