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Restriction and modification enzymes and their recognition sequences

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Introduction

Since the last compilation of restriction endonucleases (110), more than 30 Type II restriction endonucleases have been discovered, including some valuable new specificities. These include Acyl (GPuCGPyC), DdeI (CTNAG), Fnu4HI (GCNGC), RsaI (GTAC), SphI (GCAGTC), and XmaIII (CGGCCG). In addition, a number of new isoschizomers have been discovered and further information about the recognition sequences of some old entries is now available. AvaX is renamed AvaIII.

In forming this list, all endonucleases cleaving DNA at a specific sequence have been considered to be restriction enzymes although, in most cases, there is no direct genetic evidence for the presence of a restriction modification system. These endonucleases are named in accordance with the proposal of Smith and Nathans (132). Within the table, the source of each microorganism is given either as an individual or a National Culture Collection. If further information is required, it can be found either in the first reference shown which, in each case, refers to the purification procedure for the restriction enzyme, or from the individuals who have provided their unpublished results. Where more than one reference appears, the second concerns the recognition sequence for the restriction enzyme, the third contains the purification procedure for the methylase, and the fourth describes the recognition sequence for the methylase. In some cases, several references appear in one of these categories when independent groups have reached similar conclusions.

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Microorganism	Source	Enzyme[a]	Sequence[b]	Number of cleavage sites[c]				References
				λ	Ad2	SV40	ΦX174	
Achromobacter immobilis	ATCC 15934	*Aim*I	?	?	?	?	?	33
Acinetobacter calcoaceticus	R.J. Roberts	*Acc*I	GT↓$(^{A}_{C})(^{G}_{T})$AC	7	8	1	2	159
		*Acc*II (*Fnu*DII)	CGCG	>50	>50	0	14	159
Agrobacterium tumefaciens	ATCC 15955	*Atu*AI	?	>30	>30	?	?	125
Agrobacterium tumefaciens B6806	E. Nester	*Atu*BI (*Eco*RII)	CC$(^{A}_{T})$GG	>35[d]	>35	16	2	118
Agrobacterium tumefaciens IIBV7	G. Roizes	*Atu*BVI	?	>14	?	1	0	117
Agrobacterium tumefaciens ID 135	C. Kado	*Atu*II (*Eco*RII)	CC$(^{A}_{T})$GG	>35[d]	>35	16	2	79
Agrobacterium tumefaciens C58	E. Nester	*Atu*CI (*Bcl*I)	TGATCA	7[d]	5	1	0	125
Anabaena catanula	CCAP 1403/1	*Aca*I	?	?	?	?	?	62
Anabaena cylindrica	A. deWaard	*Acy*I	GPu↓CGPyC	>14	>14	0	7	27
Anabaena oscillarioides	CCAP 1403/11	*Aos*I (*Mst*I)	TGC↓GCA	>10	>15	0	1	28
		*Aos*II (*Acy*I)	GPu↓CGPyC	>14	>14	0	7	28
Anabaena subcylindrica	K. Murray	*Asu*I	G↓GNCC	>30	>30	11	2	63
		*Asu*II	?	> 5	1	0	0	112
Anabaena variabilis	K. Murray	*Ava*I	C↓PyCGPuG	8	15	0	1	100; 64
		*Ava*II	G↓G$(^{A}_{T})$CC	>17	>30	6	1	100; 140, 64, 37
		*Ava*III	ATGCAT	?	?	3	0	116; 116, 130
Anabaena variabilis[uw]	E.C. Rosenvold	*Avr*I (*Ava*I)	CPyCGPuG	8	15	0	1	119
		*Avr*II	CCTAGG	2	2	2	0	119
Arthrobacter luteus	ATCC 21606	*Alu*I	AG↓CT	>50	>50	35	24	113

Microorganism	Source	Enzyme[a]	Sequence[b]	Number of cleavage sites[c]				References
				λ	Ad2	SV40	φX174	
Arthrobacter pyridinolis	R. DiLauro	*Apy*I (*Eco*RII)	CC↓($^{A}_{T}$)GG	>35[d]	>35	16	2	29
Bacillus acidocaldarius	ATCC 27009	*Bac*I (*Sac*II)	CCGCGG	3	>25	0	1	90, 112
Bacillus amyloliquefaciens F	ATCC 23350	*Bam*FI (*Bam*HI)	GGATCC	5	3	1	0	129
Bacillus amyloliquefaciens H	F.E. Young	*Bam*HI	G↓GAT$\overset{*}{C}$C	5	3	1	0	154; 115; 57; 57
Bacillus amyloliquefaciens K	T. Kaneko	*Bam*KI (*Bam*HI)	GGATCC	5	3	1	0	129
Bacillus amyloliquefaciens N	T. Ando	*Bam*NI (*Bam*HI)	GGATCC	5	3	1	0	128
		*Bam*N$_x$ (*Ava*II)	G↓G($^{A}_{T}$)CC	>17	>30	6	1	127, 128; 67
Bacillus brevis S	A.P. Zarubina	*Bbv*SI	G$\overset{*}{C}$($^{A}_{T}$)GC	---specific methylase---				151
Bacillus brevis	ATCC 9999	*Bbv*I	G$\overset{*}{C}$($^{A}_{T}$)GC	>30	>30	23	14	46; 45; 57; 57
Bacillus caldolyticus	A. Atkinson	*Bcl*I	T↓GATCA	7[d]	5	1	0	10
Bacillus cereus	ATCC 14579	*Bce*14579	?	>10	?	?	?	129
Bacillus cereus	IAM 1229	*Bce*1229	?	>10	?	?	?	129
Bacillus cereus	T. Ando	*Bce*170 (*Pst*I)	CTGCAG	18	25	2	1	129
Bacillus cereus Rf sm st	T. Ando	*Bce*R (*Fnu*DII)	CGCG	>50	>50	0	14	129
Bacillus globigii	G.A. Wilson	*Bgl*I	GCCNNNN↓NGGC	22	12	1	0	31, 155; 6
		*Bgl*II	A↓GATCT	6	12	0	0	31, 155; 105
Bacillus megaterium 899	B899	*Bme*899	?	> 5	?	?	?	129
Bacillus megaterium B205-3	T. Kaneko	*Bme*205	?	>10	?	?	?	129
Bacillus megaterium	J. Upcroft	*Bme*I	?	>10	>20	4	?	42
Bacillus pumilus AHU1387A	T. Ando	*Bpu*I	?	6	>30	2	?	66
Bacillus sphaericus	IAM 1286	*Bsp*1286	?	?	?	?	?	129

Microorganism	Source	Enzyme[a]	Sequence[b]	Number of cleavage sites[c]				References
				λ	Ad2	SV40	ϕX174	
Bacillus sphaericus R	P. Venetianer	*Bsp*RI (*Hae*III)	GGCC	>50	>50	19	11	71
Bacillus stearothermophilus 1503-4R	N. Welker	*Bst*I (*Bam*HI)	G↓GATCC	5	3	1	0	23; 24a
Bacillus stearothermophilus 240	A. Atkinson	*Bst*AI	?	?	?	?	?	12
Bacillus stearothermophilus ET	N. Welker	*Bst*EI	?	?	?	?	?	93
		*Bst*EII	G↓GTNACC	11	8	0	0	93
		*Bst*EIII	?	> 7	?	?	?	93
Bacillus stearothermophilus	ATCC 12980	*Bst*PI (*Bst*EII)	G↓GTNACC	11	8	0	0	107
Bacillus stearothermophilus	D. Comb	*Bst*NI (*Eco*RII)	CC↓($^{A}_{T}$)GG	>35[d]	>35	16	2	124
Bacillus subtilis strain X5	T. Trautner	*Bsu*RI (*Hae*III)	GG↓$\overset{*}{C}$C	>50	>50	19	11	16; 17; 51
Bacillus subtilis Marburg 168	T. Ando	*Bsu*M	?	>10	?	?	?	129
Bacillus subtilis	ATCC 6633	*Bsu*6663	?	>20	?	?	?	129
Bacillus subtilis	IAM 1076	*Bsu*1076 (*Hae*III)	GGCC	>50	>50	19	11	129
Bacillus subtilis	IAM 1114	*Bsu*1114 (*Hae*III)	GGCC	>50	>50	19	11	129
Bacillus subtilis	IAM 1247	*Bsu*1247 (*Pst*I)	CTGCAG	18	25	2	1	129; 61
Bacillus subtilis	ATCC 14593	*Bsu*1145	?	>20	?	?	?	129
Bacillus subtilis	IAM 1192	*Bsu*1192	?	>10	?	?	?	129
Bacillus subtilis	IAM 1193	*Bsu*1193	?	>30	?	?	?	129
Bacillus subtilis	IAM 1231	*Bsu*1231	?	>20	?	?	?	129
Bacillus subtilis	IAM 1259	*Bsu*1259	?	> 8	?	?	?	129
Bordetella bronchiseptica	ATCC 19395	*Bbr*I (*Hin*dIII)	AAGCTT	6	11	6	0	112

Microorganism	Source	Enzyme[a]	Sequence[b]	Number of cleavage sites[c]				References
				λ	Ad2	SV40	φX174	
Brevibacterium albidum	ATCC 15831	BalI	TGG↓CCA	15	17	0	0	43
Brevibacterium luteum	ATCC 15830	BluI (XhoI)	C↓TCGAG	1	6	0	1	47
		BluII (HaeIII)	GGCC	>50	>50	19	11	148
Caryophanon latum L	H. Mayer	ClaI	AT↓CGAT	12	?	0	0	88
Caryophanon latum	DSM 484	CltI (HaeIII)	GG↓CC	>50	>50	19	11	90
Chloroflexus aurantiacus	A. Bingham	CauI (AvaII)	$\mathrm{GG}\binom{A}{T}\mathrm{CC}$	>30	>30	6	1	11
		CauII	?	>30	>30	0	?	11
Chromobacterium violaceum	ATCC 12472	CviI	?	?	?	?	?	33
Clostridium formicoaceticum	ATCC 23439	CfoI (HhaI)	GCGC	>50	>50	2	18	84
Corynebacterium humiferum	ATCC 21108	ChuI (HindIII)	AAGCTT	6	11	6	0	33
		ChuII (HindII)	GTPyPuAC	34	>20	7	13	33
Corynebacterium petrophilum	ATCC 19080	CpeI (BclI)	TGATCA	7^{d}	5	1	0	36
Desulfovibrio desulfuricans Norway strain	H. Peck	DdeI	C↓TNAG	>50	>50	19	14	84; 44
Diplococcus pneumoniae	S. Lacks	DpnI	$\mathrm{G}\overset{*}{\mathrm{A}}$↓TC	--only cleaves methylated DNA--			0	74; 40, 75
Diplococcus pneumoniae	S. Lacks	DpnII (MboI)	GATC	$>50^{d}$	>50	8	0	74; 75
Enterobacter cloacae	H. Hartmann	EclI	?	14	?	?	?	55
		EclII (EcoRII)	$\mathrm{CC}\binom{A}{T}\mathrm{GG}$	$>35^{d}$	>35	16	2	55
Enterobacter cloacae	DSM 30056	EcaI (BstEII)	G↓GTNACC	11	8	0	0	60
Enterobacter cloacae	DSM 30060	EccI (SacII)	CCGCGG	3	>25	0	1	89; 112
Escherichia coli RY13	R.N. Yoshimori	EcoRI	G↓$\overset{*}{\mathrm{A}}$ATTC	5	5	1	0	50; 58; 50; 30
		EcoRI'	PuPuA↓TPyPy	>10	>10	24	16	99

Microorganism	Source	Enzyme[a]	Sequence[b]	Number of cleavage sites[c]				References
				λ	Ad2	SV40	φX174	
Haemophilus suis	ATCC 19417	*Hsu*I (*Hin*dIII)	A↓AGCTT	6	11	6	0	112
Herpetosiphon giganteus HP1023	J.H. Parish	*Hgi*AI	G($^{A}_{T}$)GC($^{A}_{T}$)↓C	20	?	0	3	22
Herpetosiphon giganteus Hpg 5	H. Reichenbach	*Hgi*BI (*Ava*II)	G↓G($^{A}_{T}$)CC	>17	>30	6	1	91
Herpetosiphon giganteus Hpg 9	H. Reichenbach	*Hgi*CI	?	?	?	?	?	91
		*Hgi*CII (*Ava*II)	G↓G($^{A}_{T}$)CC	>17	>30	6	1	91
		*Hgi*CIII (*Sal*I)	G↓TCGAC	2	3	0	0	91
Herpetosiphon giganteus Hpa2	H. Reichenbach	*Hgi*DI	?	?	?	?	?	91
		*Hgi*DII (*Sal*I)	G↓TCGAC	2	3	0	0	91
Herpetosiphon giganteus Hpg 24	H. Reichenbach	*Hgi*EI (*Ava*II)	G↓G($^{A}_{T}$)CC	>17	>30	6	1	91
		*Hgi*EII	?	?	?	?	?	91
Klebsiella pneumoniae OK8	J. Davies	*Kpn*I	GGTAC↓C	2	8	1	0	131; 145
Microcoleus species	D. Comb	*Mst*I	TGCGCA	>10	>15	0	1	25; 45
		*Mst*II	?	2	> 6	0	0	123
Moraxella bovis	ATCC 10900	*Mbo*I	↓GATC	>50[d]	>50	8	0	41
		*Mbo*II	GAAGA[g]	>50	>50	16	11	41; 19, 32
Moraxella glueidi LG1	J. Davies	*Mgl*I	?	?	?	?	?	131
Moraxella glueidi LG2	J. Davies	*Mgl*II	?	?	?	?	?	131
Moraxella nonliquefaciens	ATCC 19975	*Mno*I (*Hpa*II)	C↓CGG	>50	>50	1	5	112; 5
		*Mno*II (*Mnn*III)	?	>10	> 6	3	?	112
		*Mno*III (*Mbo*I)	GATC	>50[d]	>50	8	0	112

Microorganism	Source	Enzyme[a]	Sequence[b]	Number of cleavage sites[c]				References
				λ	Ad2	SV40	φX174	
Escherichia coli R245	R.N. Yoshimori	EcoRII	$\downarrow C\overset{*}{C}\binom{A}{T}GG$	>35[d]	>35	16	2	158; 8, 13; 158; 13
Escherichia coli B	W. Arber	EcoB	$TG\overset{*}{A}(N)_8TGCT$	---Type I---				35; 77, 108; 78; 150
Escherichia coli K	M. Meselson	EcoK	$AAC(N)_6GTGC$	---Type I---				94; 7, 68; 53
Escherichia coli (PI)	K. Murray	EcoPl	$AG\overset{*}{A}CC$	--Type III[i]--		4	7	52; 4; 14, 15; 4,56
Escherichia coli P15	W. Arber	EcoP15	CAGCAG	--Type III[i]--		12	5	109; 3
Flavobacterium species	N. Brown	FspAI (BstEII)	G↓GTNACC	11	8	0	0	18
Fusobacterium nucleatum A	M. Smith	FnuAI (HinfI)	G↓ANTC	>50	>50	10	21	82
		FnuAII (MboI)	GATC	>50[d]	>50	8	0	82; 112
Fusobacterium nucleatum C	M. Smith	FnuCI (MboI)	↓GATC	>50[d]	>50	8	0	82
Fusobacterium nucleatum D	M. Smith	FnuDI (HaeIII)	GG↓CC	>50	>50	19	11	82
		FnuDII	CG↓CG	>50	>50	0	14	82
		FnuDIII (HhaI)	GCG↓C	>50	>50	2	18	82
Fusobacterium nucleatum E	M. Smith	FnuEI (MboI)	↓GATC	>50[d]	>50	8	0	82
Fusobacterium nucleatum 48	M. Smith	Fnu48 I	?	>50	?	?	>10	81
Fusobacterium nucleatum 4H	M. Smith	Fnu4H I	GC↓NGC	>50	>50	25	31	80
Haemophilus aegyptius	ATCC 11116	HaeI	$\binom{A}{T}GG\downarrow CC\binom{A}{T}$	?	?	11	6	102
		HaeII	PuGCGC↓Py	>30	>30	1	8	111; 147
		HaeIII	$GG\downarrow\overset{*}{C}C$	>50	>50	19	11	95; 17; 86; 86
Haemophilus aphrophilus	ATCC 19415	HapI	?	>30	?	?	?	112
		HapII (HpaII)	C↓CGG	>50	>50	1	5	143; 137
Haemophilus gallinarum	ATCC 14385	HgaI	GACGC[e]	>50	>50	0	14	143; 20, 136

Microorganism	Source	Enzyme[a]	Sequence[b]	Number of cleavage sites[c]				References
				λ	Ad2	SV40	φX174	
Haemophilus haemoglobinophilus	ATCC 19416	HhgI (HaeIII)	GGCC	>50	>50	19	11	112
Haemophilus haemolyticus	ATCC 10014	HhaI	G$\overset{*}{\text{C}}$G↓C	>50	>50	2	18	114; 114; 87
		HhaII (HinfI)	GANTC	>50	>50	10	21	85
Haemophilus influenzae 1056	J. Stuy	Hin1056I (FnuDII)	CGCG	>50	>50	0	14	104
		Hin1056II	?	>30	>30	0	5	104
Haemophilus influenzae serotype b, 1076	J. Stuy	HinbIII (HindIII)	AAGCTT	6	11	6	0	104
Haemophilus influenzae R$_b$	C.A. Hutchison	HinbIII (HindIII)	AAGCTT	6	11	6	0	96, 112
Haemophilus influenzae serotype c, 1160	J. Stuy	HincII (HindII)	GTPyPuAC	34	>20	7	13	104
Haemophilus influenzae serotype c, 1161	J. Stuy	HincII (HindII)	GTPyPuAC	34	>20	7	13	104
Haemophilus influenzae R$_c$	A. Landy, G. Leidy	HincII (HindII)	GTPyPuAC	34	>20	7	13	76
Haemophilus influenzae R$_d$	S.H. Goodgal (exo mutant)	HindI	C$\overset{*}{\text{A}}$C	---specific methylase---				120; 121
		HindII	GTPy↓Pu$\overset{*}{\text{A}}$C	34	>20	7	13	133, 70, 120, 121
		HindIII	$\overset{*}{\text{A}}$↓AGCTT	6	11	6	0	103; 103; 120; 121
		HindIV	G$\overset{*}{\text{A}}$C	---specific methylase---				120; 121
Haemophilus influenzae R$_f$	C.A. Hutchison	HinfI	G↓ANTC	>50	>50	10	21	96; 65, 101
		HinfII (HindIII)	AAGCTT	6	11	6	0	87
		HinfIII	?	---Type III[i]---			?	69
Haemophilus influenzae H-1	M. Takanami	HinHI (HaeII)	PuGCGCPy	>30	>30	1	8	143
Haemophilus parahaemolyticus	C.A. Hutchison	HphI	GGTGA[f]	>50	>50	4	9	96; 72
Haemophilus parainfluenzae	J. Setlow	HpaI	GTT↓AAC	13	6	4	3	126; 39
		HpaII	C↓$\overset{*}{\text{C}}$GG	>50	>50	1	5	126; 39; 86; 86

Microorganism	Source	Enzyme[a]	Sequence[b]	Number of cleavage sites[c]				References
				λ	Ad2	SV40	φX174	
Moraxella nonliquefaciens	ATCC 17953	MnlI	CCTC[h]	>50	>50	51	34	160
Moraxella nonliquefaciens	ATCC 17954	MnnI (HindII)	GTPyPuAC	34	>20	7	13	54
		MnnII (HaeIII)	GGCC	>50	>50	19	11	54
		MnnIII	?	>10	> 6	3	?	54
		MnnIV (HhaI)	GCGC	>50	>50	2	18	54
Moraxella osloensis	ATCC 19976	MosI (MboI)	GATC	>50[d]	>50	8	0	41
Moraxella species	R.J. Roberts	MspI (HpaII)	CCGG	>50	>50	1	5	149
Myxococcus stipitatus Mxs2H	H. Reichenbach	MsiI (XhoI)	CTCGAG	1	6	0	1	96, 112
Myxococcus virescens V-2	H. Reichenbach	MviI	?	1	?	?	?	98
		MviII	?	?	?	?	?	98
Neisseria gonorrhoea	G. Wilson	NgoI (HaeII)	PuGCGCPy	>30	>30	1	8	156
Neisseria gonorrhoea	CDC 66	NgoII (HaeIII)	GGCC	>50	>50	19	11	26
Oerskovia xanthineolytica	R. Shekman	OxaI (AluI)	AGCT	>50	>50	35	24	135
		OxaII	?	?	?	?	?	135
Proteus vulgaris	ATCC 13315	PvuI	CGATCG	4	7	0	0	46
		PvuII	CAG↓CTG	15	22	3	0	46
Providencia alcalifaciens	ATCC 9886	PalI (HaeIII)	GGCC	>50	>50	19	11	42
Providencia stuartii 164	J. Davies	PstI	CTGCA↓G	18	25	2	1	131; 21
Pseudomonas aeruginosa	G.A. Jacoby	PaeR7	?	1	?	0	0	59
Pseudomonas facilis	M. VanMontagu	PfaI (MboI)	GATC	>50[d]	>50	8	0	149
Pseudomonas maltophila	D. Comb	PmaI (PstI)	CTGCAG	18	25	2	1	123

Microorganism	Source	Enzyme^a	Sequence^b	Number of cleavage sites^c				References
				λ	Ad2	SV40	φX174	
Rhodopseudomonas sphaeroides	R. Lascelles	RspI	CGATCG	4	7	0	0	9
Rhodopseudomonas sphaeroides	S. Kaplan	RshI (PvuI)	CGAT↓CG	4	7	0	0	83
Rhodopseudomonas sphaeroides	S. Kaplan	RsaI	GT↓AC	>50	>50	11	17	38
Rhodopseudomonas sphaeroides	S. Kaplan	RsrI (EcoRI)	GAATTC	5	5	1	0	38
Serratia marcescens S_b	C. Mulder	SmaI	CCC↓GGG	3	12	0	0	49; 34
Serratia species SAI	B. Torheim	SspI	?	?	?	?	?	146
Sphaerotilus natans C	A. Pope	SnaI	?	2	?	?	?	106
Staphylococcus aureus 3A	E.E. Stobberingh	Sau3A (MboI)	↓GATC	>50^d	>50	8	0	138
Staphylococcus aureus PS96	E.E. Stobberingh	Sau96I (AsuI)	G↓GNCC	>30	>30	11	2	139
Streptococcus faecalis var. zymogenes	R. Wu	SfaI (HaeIII)	GG↓CC	>50	>50	19	11	157
Streptococcus faecalis ND547	D. Clewell	SfaNI	GATGC	>50^h	>30	6	12	125
Streptomyces achromogenes	ATCC 12767	SacI	GAGCT↓C	2	7	0	0	1
		SacII	CCGC↓GG	3	>25	0	1	1
		SacIII	?	>100	>100	?	?	1
Streptomyces albus	CMI 52766	SalPI (PstI)	CTGCAG	18	25	2	1	24
Streptomyces albus subspecies pathocidicus	KCC S0166	SpaI (XhoI)	CTCGAG	1	6	0	1	142
Streptomyces albus G	J.M. Ghuysen	SalI	G↓TCGAC	2	3	0	0	2
		SalII	?	>20	?	?	?	2
Streptomyces aureofaciens IKA 18/4	?	SauI	?	2	?	?	?	144
Streptomyces bobiliae	ATCC 3310	SboI (SacII)	CCGCGG	3	>25	0	1	141

Microorganism	Source	Enzyme[a]	Sequence[b]	Number of cleavage sites[c]				References
				λ	Ad2	SV40	ϕX174	
Streptomyces bradiae	ATCC 3535	SbrI (SacII)	CCGCGG	3	>25	0	1	141
Streptomyces cupidosporus	KCC S0316	ScuI (XhoI)	CTCGAG	1	6	0	1	141
Streptomyces exfoliatus	KCC S0030	SexI (XhoI)	CTCGAG	1	6	0	1	142
Streptomyces goshikiensis	KCC S0294	SgoI (XhoI)	CTCGAG	1	6	0	1	142
Streptomyces griseus	ATCC 23345	SgrI	?	0	7	0	?	1
Streptomyces hygroscopicus	F. Walter	ShyI (SacII)	CCGCGG	3	>25	0	1	152
Streptomyces lavendulae	ATCC 8644	SlaI (XhoI)	C↓TCGAG	1	6	0	1	141
Streptomyces luteoreticuli	KCC S0788	SluI (XhoI)	CTCGAG	1	6	0	1	142
Streptomyces phaeochromogenes	F. Bolivar	SphI	GCATG↓C	4	?	2	0	162
Streptomyces stanford	S. Goff, A. Rambach	SstI (SacI)	GAGCT↓C	2	7	0	0	48; 97
		SstII (SacII)	CCGC↓GG	3	>25	0	1	48
		SstIII (SacIII)	?	>100	>100	?	?	48
Thermoplasma acidophilum	D. Searcy	ThaI (FnuDII)	CG↓CG	>50	>50	0	14	92
Thermopolyspora glauca	ATCC 15345	TglI (SacII)	CCGCGG	3	>25	0	1	46
Thermus aquaticus YTI	J.I. Harris	TaqI	T↓CGA	>50	>50	1	10	122
		TaqII	?	>30	>30	4	6	112
Xanthomonas amaranthicola	ATCC 11645	XamI (SalI)	GTCGAC	2	3	0	0	2
Xanthomonas badrii	ATCC 11672	XbaI	T↓CTAGA	1^d	4	0	0	161
Xanthomonas holcicola	ATCC 13461	XhoI	C↓TCGAG	1	6	0	1	47
		XhoII	Pu↓GATCPy	>20	>20	3	0	104; 46

Microorganism	Source	Enzyme[a]	Sequence[b]	Number of cleavage sites[c]				References
				λ	Ad2	SV40	ϕX174	
Xanthomonas malvacearum	ATCC 9924	*Xma*I	C↓CCGGG	3	12	0	0	34
		*Xma*II (*Pst*I)	CTGCAG	18	25	2	1	34
		*Xma*III	C↓GGCCG	2	10	0	0	73
Xanthomonas nigromaculans	ATCC 23390	*Xni*I (*Pvu*I)	CGATCG	4	7	0	0	54
Xanthomonas oryzae	M. Ehrlich	*Xor*I (*Pst*I)	CTGCAG	18	25	2	1	153
		*Xor*II (*Pvu*I)	CGATC↓G	4	7	0	0	153
Xanthomonas papavericola	ATCC 14180	*Xpa*I (*Xho*I)	C↓TCGAG	1	6	0	1	47

Footnotes to Table

a. When two enzymes recognize the same sequence, i.e., are isoschizomers, the prototype (i.e., the first example isolated) is indicated in parentheses.

b. Recognition sequences are written from 5' → 3', only one strand being given, and the point of cleavage is indicated by an arrow (↓). When no arrow appears, the precise cleavage site has not been determined. For example, G↓GATCC is an abbreviation for

$$\begin{array}{l} 5'\ G^{\downarrow}G\ A\ T\ C\ C\ 3' \\ 3'\ C\ C\ T\ A\ G_{\uparrow}G\ 5' \end{array}$$

Bases appearing in parentheses signify that either base may occupy that position in the recognition sequence. Thus, AccI cleaves the sequence GTAGAC, GTATAC, GTCGAC, and GTCTAC. Where known, the base modified by the corresponding specific methylase is indicated by an asterisk. $\overset{*}{A}$ is N^6-methyladenosine. $\overset{*}{C}$ is 5-methylcytosine.

c. These columns indicate the frequency of cleavage by the various specific endonucleases on bacteriophage lambda DNA (λ), adenovirus-2 DNA (Ad2), simian virus 40 DNA (SV40), and φX174 Rf DNA (φX174). In the latter two cases, the sites were checked by computer search of the published sequences.

d. In most E. coli strains, bacteriophage lambda DNA is partially modified against the action of AtuBI, AtuII, AtuCI, BclI, CpeI, DpnII, EclII, EcoRII, FnuAII, FnuCI, MboI, MnoIII, MosI, and XbaI. It should be noted that FnuE I, PfaI and Sau3A are not inhibited by dam methylation; BstNI and ApyI are not inhibited by mec methylation.

e. HgaI cleaves as indicated:

$$\begin{array}{ll} 5'\ GACGCNNNNN^{\downarrow} & 3' \\ 3'\ CTGCGNNNNNNNNNN_{\uparrow} & 5' \end{array}$$

f. HphI cleaves as indicated:

$$\begin{array}{ll} 5'\ GGTGANNNNNNNN^{\downarrow} & 3' \\ 3'\ CCACTNNNNNNN_{\uparrow} & 5' \end{array}$$

g. MboII cleaves as indicated:

$$\begin{array}{ll} 5'\ GAAGANNNNNNNN^{\downarrow} & 3' \\ 3'\ CTTCTNNNNNNN_{\uparrow} & 5' \end{array}$$

h. MnlI cleaves 5 to 10 bases in the 3' direction from the recognition sequence. SfaNI cleaves an unknown number of nucleotides away from the recognition sequence.

i. EcoPI, EcoP15, and HinfIII have characteristics intermediate between those of the Type I and Type II restriction endonucleases. They are designated Type III in accordance with the suggestion of Kauc and Piekarowicz (69).

REFERENCES

1. Arrand, J.R., Myers, P.A. and Roberts, R.J. unpublished observations.
2. Arrand, J.R., Myers, P.A. and Roberts, R.J. J. Mol. Biol. 118, 127-135 (1978).
3. Bachi, B., Hadi, S. and Bickle, T., unpublished observations.
4. Bachi, B., Reiser, J. and Pirrotta, V. J. Mol. Biol. 128, 143-163 (1979).
5. Baumstark, B.R., Roberts, R.J. and RajBhandary, U.L. J. Biol. Chem. 254, 8943-8950 (1979).
6. Bickle, T., Pirrotta, V. and Ineichen, K., unpublished observations.
7. Bickle, T., Yuan, R., Pirrotta, V. and Ineichen, K., unpublished observations.
8. Bigger, C.H., Murray, K and Murray, N.E. Nature New Biology 244, 7-10 (1973).
9. Bingham, A.H.A., Atkinson, A., and Darbyshire, J., unpublished observations.
10. Bingham, A.H.A., Atkinson, T., Sciaky, D. and Roberts, R.J. Nucleic Acids Res. 5, 3457-3467 (1978).
11. Bingham, A.H.A. and Darbyshire, J., unpublished observations.
12. Bingham, A.H.A., Sharp, R.J. and Atkinson, T. unpublished observations.
13. Boyer, H.W., Chow, L.T., Dugaiczyk, A., Hedgpeth, J. and Goodman, H.M. Nature New Biology 244, 40-43 (1973).
14. Brockes, J.P. Biochem. J. 133, 629-633 (1973).
15. Brockes, J.P., Brown, P.R., and Murray, K. Biochem. J. 127, 1-10 (1972).
16. Bron, S., Murray, K., and Trautner, T.A. Mol. Gen. Genet. 143, 13-23 (1975).
17. Bron, S., and Murray, K. Mol. Gen. Genet. 143, 25-33 (1975).
18. Brown, N.L., unpublished observations.
19. Brown, N.L., Hutchison, C.A. III and Smith, M. J. Mol. Biol., in press.
20. Brown, N.L., and Smith, M. Proc. Natl. Acad. Sci. USA 74, 3213-3216 (1977).
21. Brown, N.L., and Smith, M. FEBS Letters, 65, 284-287 (1976).
22. Brown, N.L., McClelland, M. and Whitehead, P.R., unpublished observations.
23. Catterall, J. and Welker, N. J. Bacteriol. 129, 1110-1120 (1977).
24. Chater, K. Nucleic Acids Res. 4, 1989-1998 (1977).

24a. Clarke, C.M. and Hartley, B.S. Biochem. J. 177, 49-62 (1979).

25. Comb, D., Schildkraut, I., and Roberts, R.J., unpublished observations.
26. Clanton, D.J., Woodward, J.M. and Miller, R.V. J. Bacteriol. 135, 270-273 (1978).
27. DeWaard, A., Korsuize, J., van Beveren, C.P. and Maat, J. FEBS Letters 96, 106-110 (1978).
28. DeWaard, A., van Beveren, C.P., Duyvesteyn, M. and van Ormondt, H. FEBS Letters, in press.
29. DiLauro, R., unpublished observations.
30. Dugaiczyk, A. , Hedgpeth, J., Boyer, H.W. and Goodman, H.M. Biochemistry 13, 503-512 (1974).
31. Duncan, C.H., Wilson, G.A. and Young, F.E. J. Bacteriol. 134, 338-344 (1978).
32. Endow, S.A. J. Mol. Biol. 114, 441-450 (1977).
33. Endow, S.A. and Roberts, R.J. unpublished observations.
34. Endow, S.A. and Roberts, R.J. J. Mol. Biol., 112, 521-529 (1977).
35. Eskin, B. and Linn, S. J. Biol. Chem. 247, 6183-6191 (1972).

36. Fisherman, J., Gingeras, T.R. and Roberts, R.J., unpublished observations.
37. Fuchs, C., Rosenvold, E.C., Honigman, A. and Szybalski, W. Gene 4, 1-23 (1978).
38. Gardner, J.F., Cohen, L.K., Lynn, S.P. and Kaplan, S., unpublished observations.
39. Garfin, D.E. and Goodman, H.M. Biochem. Biophys. Res. Comm. 59, 108-116 (1974).
40. Geier, G.A. and Modrich, P. J. Biol. Chem. 254, 1408-1413 (1979).
41. Gelinas, R.E., Myers, P.A. and Roberts, R.J. J. Mol. Biol. 114, 169-180 (1977).
42. Gelinas, R.E., Myers, P.A. and Roberts, R.J. unpublished observations.
43. Gelinas, R.E., Myers, P.A., Weiss, G.A., Roberts, R.J. and Murray, K. J. Mol. Biol. 114, 433-440 (1977).
44. Gelinas, R.E. and Roberts, R.J. unpublished observations.
45. Gingeras, T.R., Milazzo, J.P., and Roberts, R.J. Nucleic Acids Res. 5, 4105-4127 (1978).
46. Gingeras, T.R. and Roberts, R.J., unpublished results.
47. Gingeras, T.R., Myers, P.A., Olson, J.A., Hanberg, F.A. and Roberts, R.J. J. Mol. Biol. 118, 113-122 (1978).
48. Goff, S. and Rambach, A., Gene 3, 347-352 (1978) and unpublished observations.
49. Greene, R. and Mulder, C. unpublished observations.
50. Greene, P.J., Betlach, M.C, Goodman, H.M. and Boyer, H.W. Methods Mol. Biol. 7, 87-111 (1974).
51. Gunthert, U., Freund, M. and Trautner, T.A. Abstracts of 12th FEBS Symposium, Dresden (1978).
52. Haberman, A. J. Mol. Biol., 89, 545-563 (1974).
53. Haberman, A., Heywood, J. and Meselson, M. Proc. Natl. Acad. Sci USA 69, 3138-3141 (1972).
54. Hanberg, F., Myers, P.A. and Roberts, R.J., unpublished observations.
55. Hartmann, H. and Goebel, W. FEBS Letters 80, 285-287 (1977).
56. Hattman, S., Brooks, J.E. and Masurekar, M. J. Mol. Biol. 126, 367-380 (1978).
57. Hattman, S., Keisler, T. and Gottehrer, A. J. Mol. Biol. 124, 701-711 (1978).
58. Hedgpeth, J., Goodman, H.M., and Boyer, H.W. Proc. Natl. Acad. Sci. USA 69, 3448-3452 (1972).
59. Hinkle, N.F. and Miller, R.V. Plasmid 2, 387-393 (1979).
60. Hobom, G., Schwarz, E., Melzer, M. and Mayer, H. Nucleic Acids Res., in press.
61. Hoshino, T., Uozumi, T., Horinouchi, S., Ozaki, A., Beppu, T., and Arima, K. Biochim. Biophys. Acta 479, 367-369 (1977).
62. Hughes, S.G., Bruce, T. and Murray, K. unpublished observations.
63. Hughes, S.G., Bruce, T. and Murray, K., submitted for publication.
64. Hughes, S.G. and Murray, K., submitted for publication.
65. Hutchison, C.A. and Barrell, B.G. unpublished observations.
66. Ikawa, S., Shibata, T. and Ando, T. J. Biochem. (Tokyo) 80, 1457-1460 (1976).
67. Ikawa, S., Shibata, T. and Ando, T. Agric. Biol. Chem. 43, 873-875 (1979).
68. Kan, N.C., Lautenberger, J.A., Edgell, M.H. and Hutchison, C.A. III. J. Mol. Biol. 130, 191-209 (1979).
69. Kauc, L., and Piekarowicz, A. Eur. J. Biochem 92, 417-426 (1978).

70. Kelly, T.J., Jr. and Smith, H.O. J. Mol. Biol. 51, 393-409 (1970).
71. Kiss, A., Sain, B., Csordas-Toth, E. and Venetianer, P. Gene 1, 323-329 (1977).
72. Kleid, D., Humayun, Z., Jeffrey, A. and Ptashne, A. Proc. Natl. Acad. Sci. USA 73, 293-297 (1976).
73. Kunkel, L.M., Silberklang, M. and McCarthy, B.J. J. Mol. Biol. 132, 133-139 (1979).
74. Lacks, S., and Greenberg, B. J. Biol. Chem. 250, 4060-4072 (1975).
75. Lacks, S. and Greenberg, B., J. Mol. Biol. 114, 153-168 (1977).
76. Landy, A., Ruedisueli, E., Robinson, L., Foeller, C., and Ross, W. Biochemistry 13, 2134-2142 (1974).
77. Lautenberger, J.A., Kan, N.C., Lackey, D., Linn, S., Edgell, M.H. and Hutchison, C.A. III. Proc. Natl. Acad. Sci. USA 75, 2271-2275 (1978).
78. Lautenberger, J.A., and Linn, S. J. Biol. Chem. 247, 6176-6182 (1972).
79. LeBon, J.M., Kado, C., Rosenthal, L.J. and Chirikjian, J. Proc. Natl. Acad. Sci. USA 75, 4097-4101 (1978).
80. Leung, D.W., Lui, A.C.P., Merilees, H., McBride, B.C. and Smith, M. Nucleic Acids Res. 6, 17-25 (1979).
81. Lui, A., McBride, B.C. and Smith, M., unpublished results.
82. Lui, A.C.P., McBride, B.C., Vovis, G.F. and Smith, M. Nucleic Acids Res. 6, 1-15 (1979).
83. Lynn, S.P., Cohen, L.K., Gardner, J.F. and Kaplan, S. J. Bacteriol. 138, 505-509 (1979).
84. Macula, R.A. and Meagher, R.B., unpublished observations.
85. Mann, M.B., Rao, R.N. and Smith, H.O. Gene 3, 97-112 (1978).
86. Mann, M.B. and Smith, H.O. Nucleic Acids Res. 4, 4211-4221 (1977).
87. Mann, M.B. and Smith, H.O. unpublished observations.
88. Mayer, H., Grosschedl, R., Schutte, H. and Hobom, G., unpublished observations.
89. Mayer, H. and Klaar, J., unpublished observations.
90. Mayer, H. and Schütte, H., unpublished observations.
91. Mayer, H., Schütte, H. and Hobom, G., unpublished observations.
92. McConnell, D., Searcy, D. and Sutcliffe, G., Nucleic Acids Res. 5, 1729-1739 (1978).
93. Meagher, R.B., unpublished observations.
94. Meselson, M. and Yuan, R. Nature 217, 1110-1114 (1968).
95. Middleton, J.H., Edgell, M.H. and Hutchison, C.A. III J. Virol. 10, 42-50 (1972).
96. Middleton, J.H., Stankus, P.V., Edgell, M.H. and Hutchison C.A. III, unpublished observations.
97. Muller, F., Stoffel, S. and Clarkson, S.G., unpublished observations.
98. Morris, D.W. and Parish, J.H. Arch. Microbiol. 108, 227-230 (1976).
99. Murray, K., Brown, J.S. and Bruce, S.A. unpublished observations.
100. Murray, K., Hughes, S.G., Brown, J.S. and Bruce, S. Biochem. J. 159, 317-322 (1976).
101. Murray, K. and Morrison, A. unpublished observations.
102. Murray, K., Morrison, A., Cooke, H.W. and Roberts, R.J. unpublished observations.

103. Old, R., Murray, K., and Roizes, G. J. Mol. Biol. 92, 331-339 (1975).
104. Olson, J.A., Myers, P.A. and Roberts, R.J. unpublished observations.
105. Pirrotta, V. Nucleic Acids Res 3, 1747-1760 (1976).
106. Pope, A., Lynn, S.P. and Gardner, J.F. unpublished observations.
107. Pugatsch, T. and Weber, H. Nucleic Acids Res., in press.
108. Ravetch, J.V., Horiuchi, K., and Zinder, N.D. Proc. Natl. Acad. Sci. USA 75, 2266-2270 (1978).
109. Reiser, J. and Yuan, R. J. Biol. Chem. 252, 451-456 (1977).
110. Roberts, R.J. Gene 4, 183-194 (1979).
111. Roberts, R.J., Breitmeyer, J.B., Tabachnik, N.F. and Myers, P.A. J. Mol. Biol. 91, 121-123 (1975).
112. Roberts, R.J. and Myers, P.A. unpublished observations.
113. Roberts, R.J., Myers, P.A., Morrison, A., and Murray, K. J. Mol. Biol. 102, 157-165 (1976).
114. Roberts, R.J., Myers, P.A., Morrison, A., and Murray, K. J. Mol. Biol. 103, 199-208 (1976).
115. Roberts, R.J., Wilson, G.A., and Young, F.E. Nature 265, 82-84 (1977).
116. Roizes, G., Nardeux, P-C., and Monier, R. FEBS Letters 104, 39-44 (1979).
117. Roizes, G., Pages, M., Lecou, C., Patillon, M. and Kovoor, A. Gene 6, 43-50 (1979).
118. Roizes, G., Patillon, M. and Kovoor, A. FEBS Letters 82, 69-70 (1977).
119. Rosenvold, E.C. and Szybalski, W., unpublished observations, cited in Gene 7, 217-270 (1979).
120. Roy P.H., and Smith, H.O. J. Mol. Biol. 81, 427-444 (1973).
121. Roy, P.H., and Smith, H.O. J. Mol. Biol. 81, 445-459 (1973).
122. Sato, S., Hutchison, C.A. and Harris, J.I. Proc. Natl. Acad. Sci. USA 74, 542-546 (1977).
123. Schildkraut, I., unpublished observations.
124. Schildkraut, I. and Comb, D., unpublished observations.
125. Sciaky, D. and Roberts, R.J., unpublished observations.
126. Sharp, P.A., Sugden, B. and Sambrook, J. Biochemistry 12, 3055-3063 (1973).
127. Shibata, T. and Ando, T. Mol. Gen. Genetics 138, 269-380 (1975).
128. Shibata, T. and Ando, T. Biochim. Biophys. Acta 442, 184-196 (1976).
129. Shibata, T., Ikawa, S., Kim, C. and Ando, T. J. Bacteriol. 128, 473-476 (1976).
130. Shimatake, H. and Rosenberg, M., unpublished observations.
131. Smith, D.L., Blattner, F.R., and Davies, J. Nucleic Acid Res. 3, 343-353 (1976).
132. Smith, H.O. and Nathans, D. J. Mol. Biol. 81, 419-423 (1973).
133. Smith, H.O. and Wilcox, K.W. J. Mol. Biol. 51, 379-391 (1970).
134. Stobberingh, E.E., Schiphof, R. and Sussenbach, J.S. J. Bacteriol. 131, 645-649 (1977).
135. Stotz, A. and Philippson, P., unpublished observations.
136. Sugisaki, H. Gene 3, 17-28 (1978).
137. Sugisaki, H. and Takanami, K. Nature New Biology 246, 138-140 (1973).

138. Sussenbach, J.S. Monfoort, C.H. Schiphof, R. and Stobberingh, E.E. Nucleic Acids Res. 3, 3193-3202 (1976).
139. Sussenbach, J.S., Steenbergh, P.H., Rost, J.A., Van Leeuwen, W.J. and van Embden, J.D.A. Nucleic Acids Res. 5, 1153-1163 (1978).
140. Sutcliffe, J.G. and Church, G.M., Nucleic Acids Res. 5, 2313-2319 (1978).
141. Takahashi, H., Shimizu, M., Saito, H, Ikeda, Y. and Sugisaki, H. Gene 5, 9-18 (1979).
142. Takahashi, H., unpublished observations.
143. Takanami, M. Methods in Molecular Biology 7, 113-133 (1974).
144. Timko, J., Zelinka, J. and Zelinkova, E. Abstracts of XIth Int. Congress Biochem. p. 45 (1979).
145. Tomassini, J., Roychoudhury, R., Wu, R., and Roberts, R.J., Nucleic Acids Res., 5, 4055-4064 (1978).
146. Torheim, B. personal communication.
147. Tu, C-P.D., Roychoudhury, R., and Wu, R. Biochem. Biophys. Res. Comm. 72, 355-362 (1976).
148. Van Montagu, M., unpublished observations.
149. Van Montagu, M., Sciaky, D., Myers, P.A. and Roberts, R.J., unpublished observations.
150. Van Ormondt, H., Lautenberger, J.A., Linn, S. and deWaard, A. FEBS Lett 33, 177-180 (1973).
151. Vanyushin, B.F. and Dobritsa, A.P., Biochim. Biophys. Acta, 407, 61-72 (1975).
152. Walter, F., Hartmann, M. and Roth, M. Abstracts of 12th FEBS Symposium, Dresden, (1978).
153. Wang, R.Y.-H., Shedlarski, J.G., Farber, M.B., Kuebbing, D. and Ehrlich, M. Biochim. Biophys. Acta (in press).
154. Wilson, G.A. and Young, F.E. J. Mol. Biol. 97, 123-126 (1975).
155. Wilson, G.A. and Young, F.E. in Microbiology 1976. ed. D. Schlessinger. Amer. Soc. Microbiol., Washington pp. 350-357 (1976).
156. Wilson, G.A. and Young, F.E. unpublished observations.
157. Wu, R., King, C. and Jay, E. Gene 4, 329-336 (1978).
158. Yoshimori, R.N. PhD Thesis (1971).
159. Zabeau, M. and Roberts, R.J., unpublished observations.
160. Zabeau, M., Greene, R., Myers, P.A. and Roberts, R.J. unpublished observations.
161. Zain, B.S. and Roberts, R.J. J. Mol. Biol. 115, 249-255 (1977).
162. Fuchs, L.Y., Covarrubias, L., Escalante, L., Sanchez, S. and Bolivar, F., Gene, in press.

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