Snapshot: SMC Protein Complexes I

Cell

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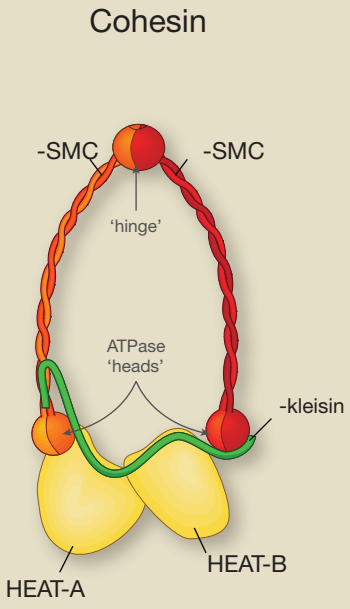
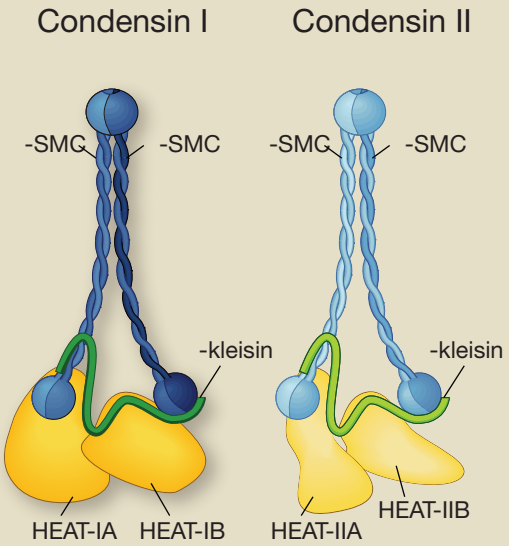
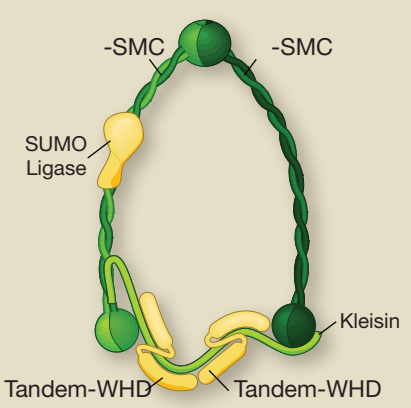
Eukaryotic SMC Complexes

		S. cerevisiae (Budding Yeasts)	*S. pombe* (Fission Yeasts)	*A. thaliana* (Plants)	*C. elegans* (Nematodes)	*D. melanogaster* (Insects)	*H. sapiens* (Vertebrates)
Cohesin							
Subunits	-SMC	Smc1	Psm1 (Smc1)	SMC1 (TTN8)	HIM-1 (SMC-1)	SMC1	SMC1α, SMC1β*
Subunits	-SMC	Smc3	Psm3 (Smc3)	SMC3	SMC-3	SMC3	SMC3
Subunits	-kleisin	Scc1 (Mcd1), ***Rec8****	Rad21, Rec8*	SYN2-4, SYN1*	SCC-1 (COH-2), COH-1 REC-8*, COH-3/4*	Rad21, C(2)M?*	SCC1, REC8*, RAD21L*
Subunits	HEAT-A	Pds5	Pds5	PDS5	EVL-14	Pds5	PDS5A, PDS5B
Subunits	HEAT-B	Scc3 (Irr1)	Psc3, Rec11*	SCC3	SCC-3	SA, SA-2 (SNM)*	SA1, SA2, SA3*
Regulators	Kollerin loading complex	Scc2	Mis4	SCC2	PQN-85 (SCC-2)	Nipped-B	NIPBL (SCC2)
Regulators	Kollerin loading complex	Scc4	Ssl3	–	MAU-2	Mau-2	MAU2 (SCC4)
Regulators	Acetyltransferase	Eco1 (Ctf7)	Eso1	ECO1 (CTF7)	F08F8.4	Eco (Deco) + San	ESCO1, ESCO2
Regulators	Deacetylase	Hos1	–	–	–	–	HDAC8
Regulators	Stabilizer	–	–	–	–	Dalmatian	Sororin (CDCA5)
Regulators	Destabilizer	Wpl1 (Rad61)	Wpl1	WAPL	WAPL-1	Wapl	WAPL
Regulators	Separase	Esp1	Cut1	ESP	SEP-1	Sse + Thr	ESPL1
Regulators	Shugoshin–phosphatase complex	Sgo1	Sgo1	SGO1	–	MEI-S332	SGOL1
Regulators	Shugoshin–phosphatase complex	PP2A	PP2A	–	–	–	PP2A
Condensin							
Subunits	-SMC	Smc4	Cut3 (Smc4)	SMC4A	SMC-4, DPY-27**	Smc4 (Gluon)	SMC4
Subunits	-SMC	Smc2	Cut14 (Smc2)	SMC2A/B	MIX-1 (SMC-2)	Smc2	SMC2
Subunits	Condensin I -kleisin	Brn1	Cnd2	CAP-H	DPY-26	Barren (Cap-H)	CAP-H
Subunits	Condensin I HEAT-IA	Ycs4	Cnd1	CAP-D2	DPY-28	Cap-D2	CAP-D2
Subunits	Condensin I HEAT-IB	Ycg1	Cnd3	CAP-G	CAPG-1	Cap-G	CAP-G
Subunits	Condensin II -kleisin	–	–	CAP-H2	KLE-2	Cap-H2	CAP-H2
Subunits	Condensin II HEAT-IIA	–	–	CAP-D3	HCP-6	Cap-D3	CAP-D3
Subunits	Condensin II HEAT-IIB	–	–	CAP-G2	CAPG-2	–	CAP-G2
Regulators	Cyclin-dependent kinase	Cdc28	Cdc2	–	–	–	CDK1
Regulators	Aurora B kinase	Ipl1	Ark1	–	AIR-2	Aurora B	Aurora B (AURKB)
Regulators	Polo-like kinase	Cdc5	–	–	–	–	PLK1
Smc5/6							
Subunits	-SMC	Smc5	Smc5 (Spr18)	SMC5	SMC-5	Smc5	SMC5
Subunits	-SMC	Smc6 (Rhc18)	Smc6 (Rad18)	SMC6A/B	SMC-6	Smc6 (Jnj)	SMC6
Subunits	Kleisin	Nse4 (Qri2)	Nse4 (Rad62)	NSE4A/B	–	Nse4	NSE4A, NSE4B
Subunits	Tandem-WHD E3 ligase	Nse1	Nse1	NSE1	–	Nse1	NSE1
Subunits	Tandem-WHD	Nse3	Nse3	NSE3	–	Mage (Nse3)	MAGE-G1 (NSE3)
Subunits	SUMO ligase	Mms21 (Nse2)	Nse2 (Pli2)	NSE2	–	Quijote, Cervante	NSE2
Co-factors		Nse5	Nse5	–	–	–	–
Co-factors		Kre29 (Nse6)	Nse6	–	–	–	SLF2
Co-factors	BRCT domain	Rtt107?	Brc1?	–	–	–	SLF1

**Meiosis-specific subunit **Specific subunit of the dosage compensation complex*

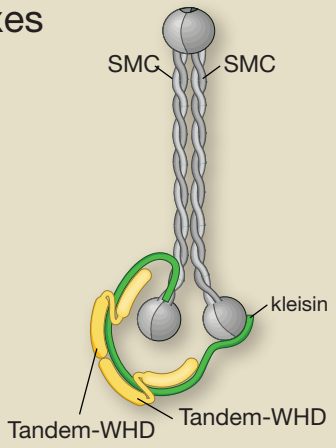




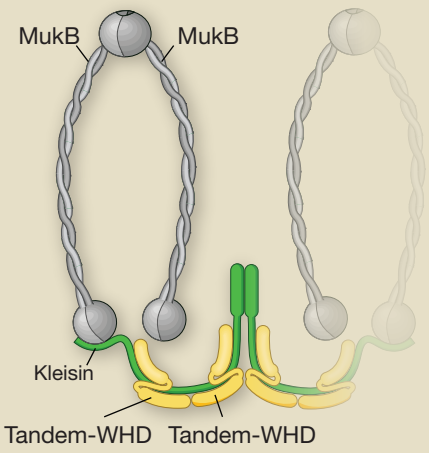


Prokaryotic SMC Complexes

		Many species (e.g. B. subtilis)
Smc-ScpAB		
Subunits	SMC	Smc
Subunits	Kleisin	ScpA
Subunits	Tandem-WHD	ScpB
Targeting		ParB/parS



		Sub-families of -proteobacteria (e.g. E. coli)	*Var. distribution (e.g. P. aeroginosa PAO1)*
MukBEF/MksBEF			
Subunits	SMC	MukB	MksB
Subunits	Kleisin	MukF	MksF
Subunits	Tandem-WHD	MukE	MksE
Co-factor		Topoisomerase IV	MksG



See online version for legend and references.

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This two-part SnapShot depicts the composition and architecture of SMC protein complexes and their regulators (in part I) and their roles at different stages of the cell cycle (in part II).

Part I: The architecture of SMC–kleisin complexes

The core of any Structural Maintenance of Chromosomes (SMC) protein complex is formed by a homo- or heterodimer of SMC proteins. A single kleisin subunit binds via its N- and C-terminal interfaces to the neck domain of a ν-SMC subunit and to the head domain of a κ-SMC subunit to create a tripartite ring-like architecture. The activities of the core complexes are regulated by diverse peripheral subunits, many of which are either composed of α-helical HEAT-repeats or Tandem Winged-Helix Domains (WHD) and associate via the kleisin protein.

In eukaryotic cells, at least three distinct SMC complexes (Cohesin, Condensin and Smc5/6) are needed for the correct segregation of chromosomes during mitotic and meiotic cell division cycles. During gametogenesis, several subunits of the Cohesin complex are substituted by paralogous proteins with specialized meiotic functions (marked by a single asterisk). In addition, specialized forms of some SMC complexes exist in most metazoans, such as Condensin I and Condensin II, or a *C. elegans*-specific Condensin I variant with roles in dosage compensation (marked by a double asterisk). Furthermore, The functions of SMC protein complexes are controlled by other regulatory proteins and through posttranslational modifications. These modifications include phosphorylation by several kinases (Polo-Like Kinase 1, Dbf4-dependent Kinase and Casein Kinase 1 for Cohesin; Cyclin-Dependent Kinase, Aurora B Kinase, Polo-Like Kinase 1, and Casein Kinase 2 for Condensin), acetylation, sumoylation, or proteolytic cleavage.

Most prokaryotic cells express a single SMC-ScpAB complex. MukBEF and MksBEF complexes found in certain bacteria feature an architecture that apparently deviates from the canonical SMC–kleisin organization. The N-terminal domain of kleisin MukF (and MksF) forms dimers and might thus be able to create structures with four or more SMC–kleisin subunits, such as tetrapartite rings or dimers of dimer (see cartoon).

ABBREVIATIONS

CDK1, Cyclin-Dependent Kinase 1; HEAT, Huntingtin, Elongation factor 3, protein phosphatase 2A, Tor1 kinase; PLK1, Polo-Like Kinase 1; SLF, Smc5/6 Localization Factor; SMC, Structural Maintenance of Chromosomes; WHD Winged-Helix Domain

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REFERENCES

Gruber, S. (2011). MukBEF on the march: taking over chromosome organization in bacteria? Mol Microbiol *81*, 855–859.

Hirano, T. (2012). Condensins: universal organizers of chromosomes with diverse functions. Genes Dev *26*, 1659–1678.

Nolivos, S., and Sherratt, D. (2014). The bacterial chromosome: architecture and action of bacterial SMC and SMC-like complexes. FEMS Microbiol. Rev. *38*, 380–392.

Schubert, V. (2009). SMC proteins and their multiple functions in higher plants. Cytogenet. Genome Res. 124, 202–214.

Verver, D.E., Hwang, G.H., Jordan, P.W., and Hamer, G. (2015). Resolving complex chromosome structures during meiosis: versatile deployment of Smc5/6. Chromosoma 1–13.

Xiong, B., and Gerton, J.L. (2010). Regulators of the cohesin network. Annu Rev Biochem *79*, 131–153.