

# Electron microscopic visualization of asymmetric precursor translocation intermediates: SecA functions as a dimer

Science China Life Sciences

September 2010, Volume 53, Issue 9, pp 1049–1056

Cover Article

First Online:

23 November 2010

Received:

23 June 2010

Accepted:

22 July 2010

DOI (Digital Object Identifier): 10.1007/s11427-010-4061-x

Cite this article as:

Tang, Y., Pan, X., Tai, P.C. et al. Sci. China Life Sci. (2010) 53: 1049.

doi:10.1007/s11427-010-4061-x

- [2 Citations](#)
- 43 Downloads

## Abstract

SecA, the ATPase of Sec translocase, mediates the post-translational translocation of preprotein through the protein-conducting channel SecYEG in the bacterial inner membrane. Here we report the structures of *Escherichia coli* Sec intermediates during preprotein translocation as visualized by electron microscopy to probe the oligomeric states of SecA during this process. We found that the translocase holoenzyme is symmetrically assembled by SecA and SecYEG on proteoliposomes, whereas the translocation intermediate 31 (I<sub>31</sub>) becomes asymmetric because of the presence of preprotein. Moreover, SecA is a dimer in these two translocation complexes. This work also shows surface topological changes in the components of translocation intermediates by immunogold labeling. The channel entry for preprotein translocation was found at the center of the I<sub>31</sub> structures. Our results indicate that the presence of preprotein introduces asymmetry into translocation intermediates, while SecA remains dimeric during the translocation process.

## Keywords

SecA   SecYEG   electron microscopy   single particle analysis

## References

1. Rapoport T A. Protein translocation across the eukaryotic endoplasmic reticulum and bacterial plasma membranes. *Nature*, 2007, 450: 663–669  
 1:CAS:528:DC%2BD2sXhtlKmtbzJ, 10.1038/nature06384, 18046402  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=18046402) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=18046402)  
[CrossRef](http://dx.doi.org/10.1038/nature06384) (http://dx.doi.org/10.1038/nature06384)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Protein%20translocation%20across%20the%20eukaryotic%20endoplasmic%20reticulum%20and%20bacterial%20plasma%20membranes&author=T.%20A.%20Rapoport&journal=Nature&volume=450&pages=663-669&publication_year=2007) (http://scholar.google.com/scholar\_lookup?title=Protein%20translocation%20across%20the%20eukaryotic%20endoplasmic%20reticulum%20and%20bacterial%20plasma%20membranes&author=T.%20A.%20Rapoport&journal=Nature&volume=450&pages=663-669&publication\_year=2007)
2. Randall L L, Topping T B, Hardy S J, *et al.* Binding of SecB to ribosome-bound polypeptides has the same characteristics as binding to full-length, denatured proteins. *Proc Natl Acad Sci USA*, 1997, 94: 802–807  
 1:CAS:528:DyaK2sXhtVOMu7w%3D, 10.1073/pnas.94.3.802, 9023337  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=9023337) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=9023337)  
[PubMedCentral](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC19594) (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC19594)  
[CrossRef](http://dx.doi.org/10.1073/pnas.94.3.802) (http://dx.doi.org/10.1073/pnas.94.3.802)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Binding%20of%20SecB%20to%20ribosome-bound%20polypeptides%20has%20the%20same%20characteristics%20as%20binding%20to%20full-length%20denatured%20proteins&author=L.%20L.%20Randall&author=T.%20B.%20Topping&author=S.%20J.%20Hardy&journal=Proc%20Natl%20Acad%20Sci%20USA&volume=94&pages=802-807&publication_year=1997) (http://scholar.google.com/scholar\_lookup?title=Binding%20of%20SecB%20to%20ribosome-bound%20polypeptides%20has%20the%20same%20characteristics%20as%20binding%20to%20full-length%20denatured%20proteins&author=L.%20L.%20Randall&author=T.%20B.%20Topping&author=S.%20J.%20Hardy&journal=Proc%20Natl%20Acad%20Sci%20USA&volume=94&pages=802-807&publication\_year=1997)
3. Economou A, Wickner W. SecA promotes preprotein translocation by undergoing ATP-driven cycles of membrane insertion and deinsertion. *Cell*, 1994, 78: 835–843 1:CAS:528:DyaK2MXptF2itw%3D%3D, 10.1016/S0092-8674(94)90582-7, 8087850  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=8087850) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=8087850)  
[CrossRef](http://dx.doi.org/10.1016/S0092-8674(94)90582-7) (http://dx.doi.org/10.1016/S0092-8674(94)90582-7)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=SecA%20promotes%20preprotein%20translocation%20by%20undergoing%20ATP-driven%20cycles%20of%20membrane%20insertion%20and%20deinsertion&author=A.%20Economou&author=W.%20Wickner&journal=Cell&volume=78&pages=835-843&publication_year=1994) (http://scholar.google.com/scholar\_lookup?title=SecA%20promotes%20preprotein%20translocation%20by%20undergoing%20ATP-driven%20cycles%20of%20membrane%20insertion%20and%20deinsertion&author=A.%20Economou&author=W.%20Wickner&journal=Cell&volume=78&pages=835-843&publication\_year=1994)
4. Schiebel E, Driessen A J, Hartl F U, *et al.* Delta mu H<sup>+</sup> and ATP function at different steps of the catalytic cycle of preprotein translocase. *Cell*, 1991, 64: 927–939 1:CAS:528:DyaK3MXhvVSnruc%3D, 10.1016/0092-8674(91)90317-R, 1825804  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=1825804) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=1825804)  
[CrossRef](http://dx.doi.org/10.1016/0092-8674(91)90317-R) (http://dx.doi.org/10.1016/0092-8674(91)90317-R)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Delta%20mu%20H%2B%20and%20ATP%20function%20at%20different) (http://scholar.google.com/scholar\_lookup?title=Delta%20mu%20H%2B%20and%20ATP%20function%20at%20different)

%20steps%20of%20the%20catalytic%20cycle%20of%20preprotein%20translocation&author=E.%20Schiebel&author=A.%20J.%20Driessen&author=F.%20U..%20Hartl&journal=Cell&volume=64&pages=927-939&publication\_year=1991)

5. Triplett T L, Sgrignoli A R, Gao F B, *et al.* Functional signal peptides bind a soluble N-terminal fragment of SecA and inhibit its ATPase activity. *J Biol Chem*, 2001, 276: 19648–19655 1:CAS:528:DC%2BD3MXkt12rtbo%3D, 10.1074/jbc.M100098200, 11279006  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=11279006) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=11279006)  
[CrossRef](http://dx.doi.org/10.1074/jbc.M100098200) (http://dx.doi.org/10.1074/jbc.M100098200)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Functional%20signal%20peptides%20bind%20a%20soluble%20N-terminal%20fragment%20of%20SecA%20and%20inhibit%20its%20ATPase%20activity&author=T.%20L.%20Triplett&author=A.%20R.%20Sgrignoli&author=F.%20B.%20Gao&journal=J%20Biol%20Chem&volume=276&pages=19648-19655&publication_year=2001) (http://scholar.google.com/scholar\_lookup?title=Functional%20signal%20peptides%20bind%20a%20soluble%20N-terminal%20fragment%20of%20SecA%20and%20inhibit%20its%20ATPase%20activity&author=T.%20L.%20Triplett&author=A.%20R.%20Sgrignoli&author=F.%20B.%20Gao&journal=J%20Biol%20Chem&volume=276&pages=19648-19655&publication\_year=2001)
6. Baud C, Karamanou S, Sianidis G, *et al.* Allosteric communication between signal peptides and the SecA protein DEAD motor ATPase domain. *J Biol Chem*, 2002, 277: 13724–13731 1:CAS:528:DC%2BD38XjsFWns70%3D, 10.1074/jbc.M200047200, 11825907  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=11825907) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=11825907)  
[CrossRef](http://dx.doi.org/10.1074/jbc.M200047200) (http://dx.doi.org/10.1074/jbc.M200047200)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Allosteric%20communication%20between%20signal%20peptides%20and%20the%20SecA%20protein%20DEAD%20motor%20ATPase%20domain&author=C.%20Baud&author=S.%20Karamanou&author=G.%20Sianidis&journal=J%20Biol%20Chem&volume=277&pages=13724-13731&publication_year=2002) (http://scholar.google.com/scholar\_lookup?title=Allosteric%20communication%20between%20signal%20peptides%20and%20the%20SecA%20protein%20DEAD%20motor%20ATPase%20domain&author=C.%20Baud&author=S.%20Karamanou&author=G.%20Sianidis&journal=J%20Biol%20Chem&volume=277&pages=13724-13731&publication\_year=2002)
7. Economou A. Bacterial secretome: the assembly manual and operating instructions (Review). *Mol Membr Biol*, 2002, 19: 159–169 1:CAS:528:DC%2BD38XovVCru70%3D, 10.1080/09687680210152609, 12463716  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=12463716) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=12463716)  
[CrossRef](http://dx.doi.org/10.1080/09687680210152609) (http://dx.doi.org/10.1080/09687680210152609)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Bacterial%20secretome%3A%20the%20assembly%20manual%20and%20operating%20instructions%20%28Review%29&author=A.%20Economou&journal=Mol%20Membr%20Biol&volume=19&pages=159-169&publication_year=2002) (http://scholar.google.com/scholar\_lookup?title=Bacterial%20secretome%3A%20the%20assembly%20manual%20and%20operating%20instructions%20%28Review%29&author=A.%20Economou&journal=Mol%20Membr%20Biol&volume=19&pages=159-169&publication\_year=2002)
8. Or E, Boyd D, Gon S, *et al.* The bacterial ATPase SecA functions as a monomer in protein translocation. *J Biol Chem*, 2005, 280: 9097–9105 1:CAS:528:DC%2BD2MXitVCitLo%3D, 10.1074/jbc.M413947200, 15618215  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=15618215) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=15618215)  
[CrossRef](http://dx.doi.org/10.1074/jbc.M413947200) (http://dx.doi.org/10.1074/jbc.M413947200)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=The%20bacterial%20ATPase%20SecA%20functions%20as%20a%20monomer%20in%20protein%20translocation&author=E.%20Or&author=D.%20B) (http://scholar.google.com/scholar\_lookup?title=The%20bacterial%20ATPase%20SecA%20functions%20as%20a%20monomer%20in%20protein%20translocation&author=E.%20Or&author=D.%20B)

oyd&author=S.%20Gon&journal=J%20Biol%20Chem&volume=280&pages=9097-9105&publication\_year=2005)

9. Or E, Navon A, Rapoport T. Dissociation of the dimeric SecA ATPase during protein translocation across the bacterial membrane. *Embo J*, 2002, 21: 4470–4479 1:CAS:528:DC%2BD38Xms1Kms7s%3D, 10.1093/emboj/cdf471, 12198149  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=12198149) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=12198149)  
[PubMedCentral](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC126201) (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC126201)  
[CrossRef](http://dx.doi.org/10.1093/emboj/cdf471) (http://dx.doi.org/10.1093/emboj/cdf471)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Dissociation%20of%20the%20dimeric%20SecA%20ATPase%20during%20protein%20translocation%20across%20the%20bacterial%20membrane&author=E.%20Or&author=A.%20Navon&author=T.%20Rapoport&journal=Embo%20J&volume=21&pages=4470-4479&publication_year=2002) (http://scholar.google.com/scholar\_lookup?title=Dissociation%20of%20the%20dimeric%20SecA%20ATPase%20during%20protein%20translocation%20across%20the%20bacterial%20membrane&author=E.%20Or&author=A.%20Navon&author=T.%20Rapoport&journal=Embo%20J&volume=21&pages=4470-4479&publication\_year=2002)
10. de Keyzer J, van der Sluis E O, Spelbrink R E, *et al.* Covalently dimerized SecA is functional in protein translocation. *J Biol Chem*, 2005, 280: 35255–35260 10.1074/jbc.M506157200, 16115882  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=16115882) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=16115882)  
[CrossRef](http://dx.doi.org/10.1074/jbc.M506157200) (http://dx.doi.org/10.1074/jbc.M506157200)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Covalently%20dimerized%20SecA%20is%20functional%20in%20protein%20translocation&author=J.%20Keyzer&author=E.%20O.%20Sluis&author=R.%20E.%20Spelbrink&journal=J%20Biol%20Chem&volume=280&pages=35255-35260&publication_year=2005) (http://scholar.google.com/scholar\_lookup?title=Covalently%20dimerized%20SecA%20is%20functional%20in%20protein%20translocation&author=J.%20Keyzer&author=E.%20O.%20Sluis&author=R.%20E.%20Spelbrink&journal=J%20Biol%20Chem&volume=280&pages=35255-35260&publication\_year=2005)
11. Jilaveanu L B, Zito C R, Oliver D. Dimeric SecA is essential for protein translocation. *Proc Natl Acad Sci USA*, 2005, 102: 7511–7516 1:CAS:528:DC%2BD2MXkslOntLo%3D, 10.1073/pnas.0502774102, 15897468  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=15897468) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=15897468)  
[PubMedCentral](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1140455) (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1140455)  
[CrossRef](http://dx.doi.org/10.1073/pnas.0502774102) (http://dx.doi.org/10.1073/pnas.0502774102)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Dimeric%20SecA%20is%20essential%20for%20protein%20translocation&author=L.%20B.%20Jilaveanu&author=C.%20R.%20Zito&author=D.%20Oliver&journal=Proc%20Natl%20Acad%20Sci%20USA&volume=102&pages=7511-7516&publication_year=2005) (http://scholar.google.com/scholar\_lookup?title=Dimeric%20SecA%20is%20essential%20for%20protein%20translocation&author=L.%20B.%20Jilaveanu&author=C.%20R.%20Zito&author=D.%20Oliver&journal=Proc%20Natl%20Acad%20Sci%20USA&volume=102&pages=7511-7516&publication\_year=2005)
12. Wang H, Na B, Yang H, *et al.* Additional *in vitro* and *in vivo* evidence for SecA functioning as dimers in the membrane: dissociation into monomers is not essential for protein translocation in *Escherichia coli*. *J Bacteriol*, 2008, 190: 1413–1418 1:CAS:528:DC%2BD1cXhvVolsLo%3D, 10.1128/JB.01633-07, 18065528  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=18065528) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=18065528)  
[PubMedCentral](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2238208) (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2238208)  
[CrossRef](http://dx.doi.org/10.1128/JB.01633-07) (http://dx.doi.org/10.1128/JB.01633-07)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Additional%20in%20vitro%20and%20in%20vivo%20evidence%20for%20SecA%20functioning%20as%20dimers%20in%20the%20membrane%3A%20dissociation%20into%20monomers%20is%20not%20essential%20for%20protein%20translocation%20in%20Escherichia%20coli&author=H.%20Wang&au) (http://scholar.google.com/scholar\_lookup?title=Additional%20in%20vitro%20and%20in%20vivo%20evidence%20for%20SecA%20functioning%20as%20dimers%20in%20the%20membrane%3A%20dissociation%20into%20monomers%20is%20not%20essential%20for%20protein%20translocation%20in%20Escherichia%20coli&author=H.%20Wang&au)

thor=B..%20Na&author=H..%20Yang&journal=J%20Bacteriol&volume=190&pages=1413-1418&publication\_year=2008)

13. Das S, Stivison E, Folta-Stogniew E, *et al.* Reexamination of the role of the amino terminus of SecA in promoting its dimerization and functional state. *J Bacteriol*, 2008, 190: 7302–7307 1:CAS:528:DC%2BD1cXhtlajtLnO, 10.1128/JB.00593-08, 18723626  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=18723626) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=18723626)  
[PubMedCentral](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2580686) (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2580686)  
[CrossRef](http://dx.doi.org/10.1128/JB.00593-08) (http://dx.doi.org/10.1128/JB.00593-08)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Reexamination%20of%20the%20role%20of%20the%20amino%20terminus%20of%20SecA%20in%20promoting%20its%20dimerization%20and%20functional%20state&author=S..%20Das&author=E..%20Stivison&author=E..%20Folta-Stogniew&journal=J%20Bacteriol&volume=190&pages=7302-7307&publication_year=2008) (http://scholar.google.com/scholar\_lookup?title=Reexamination%20of%20the%20role%20of%20the%20amino%20terminus%20of%20SecA%20in%20promoting%20its%20dimerization%20and%20functional%20state&author=S..%20Das&author=E..%20Stivison&author=E..%20Folta-Stogniew&journal=J%20Bacteriol&volume=190&pages=7302-7307&publication\_year=2008)
14. Papanikou E, Karamanou S, Economou A. Bacterial protein secretion through the translocase nanomachine. *Nat Rev Microbiol*, 2007, 5: 839–851 1:CAS:528:DC%2BD2sXhtFKltbzN, 10.1038/nrmicro1771, 17938627  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=17938627) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=17938627)  
[CrossRef](http://dx.doi.org/10.1038/nrmicro1771) (http://dx.doi.org/10.1038/nrmicro1771)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Bacterial%20protein%20secretion%20through%20the%20translocase%20nanomachine&author=E..%20Papanikou&author=S..%20Karamanou&author=A..%20Economou&journal=Nat%20Rev%20Microbiol&volume=5&pages=839-851&publication_year=2007) (http://scholar.google.com/scholar\_lookup?title=Bacterial%20protein%20secretion%20through%20the%20translocase%20nanomachine&author=E..%20Papanikou&author=S..%20Karamanou&author=A..%20Economou&journal=Nat%20Rev%20Microbiol&volume=5&pages=839-851&publication\_year=2007)
15. Chen Y, Pan X, Tang Y, *et al.* Full-length *Escherichia coli* SecA dimerizes in a closed conformation in solution as determined by cryo-electron microscopy. *J Biol Chem*, 2008, 283: 28783–28787 1:CAS:528:DC%2BD1cXht1GlsLbL, 10.1074/jbc.C800160200, 18772144  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=18772144) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=18772144)  
[PubMedCentral](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2570880) (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2570880)  
[CrossRef](http://dx.doi.org/10.1074/jbc.C800160200) (http://dx.doi.org/10.1074/jbc.C800160200)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Full-length%20Escherichia%20coli%20SecA%20dimerizes%20in%20a%20closed%20conformation%20in%20solution%20as%20determined%20by%20cryo-electron%20microscopy&author=Y..%20Chen&author=X..%20Pan&author=Y..%20Tang&journal=J%20Biol%20Chem&volume=283&pages=28783-28787&publication_year=2008) (http://scholar.google.com/scholar\_lookup?title=Full-length%20Escherichia%20coli%20SecA%20dimerizes%20in%20a%20closed%20conformation%20in%20solution%20as%20determined%20by%20cryo-electron%20microscopy&author=Y..%20Chen&author=X..%20Pan&author=Y..%20Tang&journal=J%20Biol%20Chem&volume=283&pages=28783-28787&publication\_year=2008)
16. Meyer T H, Menetret J F, Breitling R, *et al.* The bacterial SecY/E translocation complex forms channel-like structures similar to those of the eukaryotic Sec61p complex. *J Mol Biol*, 1999, 285: 1789–1800 1:CAS:528:DyaK1MXhtV2htLk%3D, 10.1006/jmbi.1998.2413, 9917412  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=9917412) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=9917412)  
[CrossRef](http://dx.doi.org/10.1006/jmbi.1998.2413) (http://dx.doi.org/10.1006/jmbi.1998.2413)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=The%20bacterial%20SecY%2FE%20translocation%20complex%20forms%20channel-like%20structures%20similar%20to%20those%20of%20the%20eukaryotic%20) (http://scholar.google.com/scholar\_lookup?title=The%20bacterial%20SecY%2FE%20translocation%20complex%20forms%20channel-like%20structures%20similar%20to%20those%20of%20the%20eukaryotic%20

Sec61p%20complex&author=T.%20H..%20Meyer&author=J.%20F..%20Menetret&author=R..%20Breitling&journal=J%20Mol%20Biol&volume=285&pages=1789-1800&publication\_year=1999)

17. Scheuring J, Braun N, Nothdurft L, *et al.* The oligomeric distribution of SecYEG is altered by SecA and translocation ligands. *J Mol Biol*, 2005, 354: 258–271  
1:CAS:528:DC%2BD2MXht1Sqt7vO, 10.1016/j.jmb.2005.09.058, 16242710  
[PubMed](#) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=16242710](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=16242710))  
[CrossRef](#) (<http://dx.doi.org/10.1016/j.jmb.2005.09.058>)  
[Google Scholar](#) ([http://scholar.google.com/scholar\\_lookup?title=The%20oligomeric%20distribution%20of%20SecYEG%20is%20altered%20by%20SecA%20and%20translocation%20ligands&author=J..%20Scheuring&author=N..%20Braun&author=L.%20Nothdurft&journal=J%20Mol%20Biol&volume=354&pages=258-271&publication\\_year=2005](http://scholar.google.com/scholar_lookup?title=The%20oligomeric%20distribution%20of%20SecYEG%20is%20altered%20by%20SecA%20and%20translocation%20ligands&author=J..%20Scheuring&author=N..%20Braun&author=L.%20Nothdurft&journal=J%20Mol%20Biol&volume=354&pages=258-271&publication_year=2005))
18. Osborne A R, Rapoport T A. Protein translocation is mediated by oligomers of the SecY complex with one SecY copy forming the channel. *Cell*, 2007, 129: 97–110  
1:CAS:528:DC%2BD2sXkvVeltLs%3D, 10.1016/j.cell.2007.02.036, 17418789  
[PubMed](#) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=17418789](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=17418789))  
[CrossRef](#) (<http://dx.doi.org/10.1016/j.cell.2007.02.036>)  
[Google Scholar](#) ([http://scholar.google.com/scholar\\_lookup?title=Protein%20translocation%20is%20mediated%20by%20oligomers%20of%20the%20SecY%20complex%20with%20one%20SecY%20copy%20forming%20the%20channel&author=A.%20R..%20Osborne&author=T.%20A..%20Rapoport&journal=Cell&volume=129&pages=97-110&publication\\_year=2007](http://scholar.google.com/scholar_lookup?title=Protein%20translocation%20is%20mediated%20by%20oligomers%20of%20the%20SecY%20complex%20with%20one%20SecY%20copy%20forming%20the%20channel&author=A.%20R..%20Osborne&author=T.%20A..%20Rapoport&journal=Cell&volume=129&pages=97-110&publication_year=2007))
19. Tani K, Tokuda H, Mizushima S. Translocation of ProOmpA possessing an intramolecular disulfide bridge into membrane vesicles of *Escherichia coli*. Effect of membrane energization. *J Biol Chem*, 1990, 265: 17341–17347  
1:CAS:528:DyaK3cXmtVKtrg%3D  
[PubMed](#) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=2211627](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=2211627))  
[Google Scholar](#) ([http://scholar.google.com/scholar\\_lookup?title=Translocation%20of%20ProOmpA%20possessing%20an%20intramolecular%20disulfide%20bridge%20into%20membrane%20vesicles%20of%20Escherichia%20coli&author=K.%20Tani&author=H..%20Tokuda&author=S..%20Mizushima&journal=Effect%20of%20membrane%20energization.%20J%20Biol%20Chem&volume=265&pages=17341-17347&publication\\_year=1990](http://scholar.google.com/scholar_lookup?title=Translocation%20of%20ProOmpA%20possessing%20an%20intramolecular%20disulfide%20bridge%20into%20membrane%20vesicles%20of%20Escherichia%20coli&author=K.%20Tani&author=H..%20Tokuda&author=S..%20Mizushima&journal=Effect%20of%20membrane%20energization.%20J%20Biol%20Chem&volume=265&pages=17341-17347&publication_year=1990))
20. Manting E H, van Der Does C, Remigy H, *et al.* SecYEG assembles into a tetramer to form the active protein translocation channel. *Embo J*, 2000, 19: 852–861  
1:CAS:528:DC%2BD3cXitVyku7s%3D, 10.1093/emboj/19.5.852, 10698927  
[PubMed](#) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=10698927](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=10698927))  
[PubMedCentral](#) (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC305625>)  
[CrossRef](#) (<http://dx.doi.org/10.1093/emboj/19.5.852>)  
[Google Scholar](#) ([http://scholar.google.com/scholar\\_lookup?title=SecYEG%20assembles%20into%20a%20tetramer%20to%20form%20the%20active%20protein%20translocation%20channel&author=E.%20H..%20Manting&author=C..%20Does&author=H..%20Remigy&journal=Embo%20J&volume=19&pages=852-861&publication\\_year=2000](http://scholar.google.com/scholar_lookup?title=SecYEG%20assembles%20into%20a%20tetramer%20to%20form%20the%20active%20protein%20translocation%20channel&author=E.%20H..%20Manting&author=C..%20Does&author=H..%20Remigy&journal=Embo%20J&volume=19&pages=852-861&publication_year=2000))

21. Yahr T L, Wickner W T. Evaluating the oligomeric state of SecYEG in preprotein translocase. *Embo J*, 2000, 19: 4393–4401  
 1:CAS:528:DC%2BD3cXnt1yr78%3D, 10.1093/emboj/19.16.4393, 10944122  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=10944122) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=10944122)  
[PubMedCentral](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC302025) (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC302025)  
[CrossRef](http://dx.doi.org/10.1093/emboj/19.16.4393) (http://dx.doi.org/10.1093/emboj/19.16.4393)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Evaluating%20the%20oligomeric%20state%20of%20SecYEG%20in%20preprotein%20translocase&author=T.%20L.%20Yahr&author=W.%20T.%20Wickner&journal=Embo%20J&volume=19&pages=4393-4401&publication_year=2000) (http://scholar.google.com/scholar\_lookup?title=Evaluating%20the%20oligomeric%20state%20of%20SecYEG%20in%20preprotein%20translocase&author=T.%20L.%20Yahr&author=W.%20T.%20Wickner&journal=Embo%20J&volume=19&pages=4393-4401&publication\_year=2000)
22. Bessonneau P, Besson V, Collinson I, *et al.* The SecYEG preprotein translocation channel is a conformationally dynamic and dimeric structure. *Embo J*, 2002, 21: 995–1003 1:CAS:528:DC%2BD38XitFylsbo%3D, 10.1093/emboj/21.5.995, 11867527  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=11867527) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=11867527)  
[PubMedCentral](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC125904) (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC125904)  
[CrossRef](http://dx.doi.org/10.1093/emboj/21.5.995) (http://dx.doi.org/10.1093/emboj/21.5.995)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=The%20SecYEG%20preprotein%20translocation%20channel%20is%20a%20conformationally%20dynamic%20and%20dimeric%20structure&author=P.%20Bessonneau&author=V.%20Besson&author=I.%20Collinson&journal=Embo%20J&volume=21&pages=995-1003&publication_year=2002) (http://scholar.google.com/scholar\_lookup?title=The%20SecYEG%20preprotein%20translocation%20channel%20is%20a%20conformationally%20dynamic%20and%20dimeric%20structure&author=P.%20Bessonneau&author=V.%20Besson&author=I.%20Collinson&journal=Embo%20J&volume=21&pages=995-1003&publication\_year=2002)
23. Collinson I, Breyton C, Duong F, *et al.* Projection structure and oligomeric properties of a bacterial core protein translocase. *Embo J*, 2001, 20: 2462–2471 1:CAS:528:DC%2BD3MXktFegu70%3D, 10.1093/emboj/20.10.2462, 11350935  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=11350935) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=11350935)  
[PubMedCentral](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC125464) (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC125464)  
[CrossRef](http://dx.doi.org/10.1093/emboj/20.10.2462) (http://dx.doi.org/10.1093/emboj/20.10.2462)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Projection%20structure%20and%20oligomeric%20properties%20of%20a%20bacterial%20core%20protein%20translocase&author=I.%20Collinson&author=C.%20Breyton&author=F.%20Duong&journal=Embo%20J&volume=20&pages=2462-2471&publication_year=2001) (http://scholar.google.com/scholar\_lookup?title=Projection%20structure%20and%20oligomeric%20properties%20of%20a%20bacterial%20core%20protein%20translocase&author=I.%20Collinson&author=C.%20Breyton&author=F.%20Duong&journal=Embo%20J&volume=20&pages=2462-2471&publication\_year=2001)
24. Zimmer J, Nam Y, Rapoport T A. Structure of a complex of the ATPase SecA and the protein-translocation channel. *Nature*, 2008, 455: 936–943 1:CAS:528:DC%2BD1cXht1GgurrO, 10.1038/nature07335, 18923516  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=18923516) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=18923516)  
[CrossRef](http://dx.doi.org/10.1038/nature07335) (http://dx.doi.org/10.1038/nature07335)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Structure%20of%20a%20complex%20of%20the%20ATPase%20SecA%20and%20the%20protein-translocation%20channel&author=J.%20Zimmer&author=Y.%20Nam&author=T.%20A.%20Rapoport&journal=Nature&volume=455&pages=936-943&publication_year=2008) (http://scholar.google.com/scholar\_lookup?title=Structure%20of%20a%20complex%20of%20the%20ATPase%20SecA%20and%20the%20protein-translocation%20channel&author=J.%20Zimmer&author=Y.%20Nam&author=T.%20A.%20Rapoport&journal=Nature&volume=455&pages=936-943&publication\_year=2008)
25. Wang H W, Chen Y, Yang H, *et al.* Ring-like pore structures of SecA: implication for bacterial protein-conducting channels. *Proc Natl Acad Sci USA*,

2003, 100: 4221–4226 1:CAS:528:DC%2BD3sXivFWjs7k%3D,  
 10.1073/pnas.0737415100, 12642659  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=12642659) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=12642659](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=12642659))  
[PubMedCentral](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC153074) (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC153074>)  
[CrossRef](http://dx.doi.org/10.1073/pnas.0737415100) (<http://dx.doi.org/10.1073/pnas.0737415100>)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Ring-like%20pore%20structures%20of%20SecA%3A%20implication%20for%20bacterial%20protein-conducting%20channels&author=H.%20Wang&author=Y.%20Chen&author=H.%20Yang&journal=Proc%20Nat%20Acad%20Sci%20USA&volume=100&pages=4221-4226&publication_year=2003) ([http://scholar.google.com/scholar\\_lookup?title=Ring-like%20pore%20structures%20of%20SecA%3A%20implication%20for%20bacterial%20protein-conducting%20channels&author=H.%20Wang&author=Y.%20Chen&author=H.%20Yang&journal=Proc%20Nat%20Acad%20Sci%20USA&volume=100&pages=4221-4226&publication\\_year=2003](http://scholar.google.com/scholar_lookup?title=Ring-like%20pore%20structures%20of%20SecA%3A%20implication%20for%20bacterial%20protein-conducting%20channels&author=H.%20Wang&author=Y.%20Chen&author=H.%20Yang&journal=Proc%20Nat%20Acad%20Sci%20USA&volume=100&pages=4221-4226&publication_year=2003))

26. Nishiyama K, Suzuki T, Tokuda H. Inversion of the membrane topology of SecG coupled with SecA-dependent preprotein translocation. *Cell*, 1996, 85: 71–81 1:CAS:528:DyaK28Xit1aksbs%3D, 10.1016/S0092-8674(00)81083-1, 8620539  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=8620539) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=8620539](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=8620539))  
[CrossRef](http://dx.doi.org/10.1016/S0092-8674(00)81083-1) ([http://dx.doi.org/10.1016/S0092-8674\(00\)81083-1](http://dx.doi.org/10.1016/S0092-8674(00)81083-1))  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Inversion%20of%20the%20membrane%20topology%20of%20SecG%20coupled%20with%20SecA-dependent%20preprotein%20translocation&author=K.%20Nishiyama&author=T.%20Suzuki&author=H.%20Tokuda&journal=Cell&volume=85&pages=71-81&publication_year=1996) ([http://scholar.google.com/scholar\\_lookup?title=Inversion%20of%20the%20membrane%20topology%20of%20SecG%20coupled%20with%20SecA-dependent%20preprotein%20translocation&author=K.%20Nishiyama&author=T.%20Suzuki&author=H.%20Tokuda&journal=Cell&volume=85&pages=71-81&publication\\_year=1996](http://scholar.google.com/scholar_lookup?title=Inversion%20of%20the%20membrane%20topology%20of%20SecG%20coupled%20with%20SecA-dependent%20preprotein%20translocation&author=K.%20Nishiyama&author=T.%20Suzuki&author=H.%20Tokuda&journal=Cell&volume=85&pages=71-81&publication_year=1996))
27. Yoshihisa T, Ito K. Pro-OmpA derivatives with a His6 tag in their N-terminal “translocation initiation domains” are arrested by Ni<sup>2+</sup> at an early post-targeting stage of translocation. *J Biol Chem*, 1996, 271: 9429–9436 1:CAS:528:DyaK28XisFSmurw%3D, 10.1074/jbc.271.16.9429, 8621611  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=8621611) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=8621611](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=8621611))  
[CrossRef](http://dx.doi.org/10.1074/jbc.271.16.9429) (<http://dx.doi.org/10.1074/jbc.271.16.9429>)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Pro-OmpA%20derivatives%20with%20a%20His6%20tag%20in%20their%20N-terminal%20%E2%80%9Ctranslocation%20initiation%20domains%E2%80%9C%20are%20arrested%20by%20Ni%2B%20at%20an%20early%20post-targeting%20stage%20of%20translocation&author=T.%20Yoshihisa&author=K.%20Ito&journal=J%20Biol%20Chem&volume=271&pages=9429-9436&publication_year=1996) ([http://scholar.google.com/scholar\\_lookup?title=Pro-OmpA%20derivatives%20with%20a%20His6%20tag%20in%20their%20N-terminal%20%E2%80%9Ctranslocation%20initiation%20domains%E2%80%9C%20are%20arrested%20by%20Ni%2B%20at%20an%20early%20post-targeting%20stage%20of%20translocation&author=T.%20Yoshihisa&author=K.%20Ito&journal=J%20Biol%20Chem&volume=271&pages=9429-9436&publication\\_year=1996](http://scholar.google.com/scholar_lookup?title=Pro-OmpA%20derivatives%20with%20a%20His6%20tag%20in%20their%20N-terminal%20%E2%80%9Ctranslocation%20initiation%20domains%E2%80%9C%20are%20arrested%20by%20Ni%2B%20at%20an%20early%20post-targeting%20stage%20of%20translocation&author=T.%20Yoshihisa&author=K.%20Ito&journal=J%20Biol%20Chem&volume=271&pages=9429-9436&publication_year=1996))
28. van der Does C, de Keyzer J, van der Laan M, *et al.* Reconstitution of purified bacterial preprotein translocase in liposomes. *Methods Enzymol*, 2003, 372: 86–98 10.1016/S0076-6879(03)72005-9, 14610808  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=14610808) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=14610808](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=14610808))  
[CrossRef](http://dx.doi.org/10.1016/S0076-6879(03)72005-9) ([http://dx.doi.org/10.1016/S0076-6879\(03\)72005-9](http://dx.doi.org/10.1016/S0076-6879(03)72005-9))  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Reconstitution%20of%20purified%20bacterial%20preprotein%20translocase%20in%20liposomes&author=C.%20Does&author=J.%20Keyzer&author=M.%20Laan&journal=Methods%20Enzymol&volume=372&pages=86-98&publication_year=2003) ([http://scholar.google.com/scholar\\_lookup?title=Reconstitution%20of%20purified%20bacterial%20preprotein%20translocase%20in%20liposomes&author=C.%20Does&author=J.%20Keyzer&author=M.%20Laan&journal=Methods%20Enzymol&volume=372&pages=86-98&publication\\_year=2003](http://scholar.google.com/scholar_lookup?title=Reconstitution%20of%20purified%20bacterial%20preprotein%20translocase%20in%20liposomes&author=C.%20Does&author=J.%20Keyzer&author=M.%20Laan&journal=Methods%20Enzymol&volume=372&pages=86-98&publication_year=2003))
29. Snyders S, Ramamurthy V, Oliver D. Identification of a region of interaction between *Escherichia coli* SecA and SecY proteins. *J Biol Chem*, 1997, 272:

11302–11306 1:CAS:528:DyaK2sXjtVamtbo%3D, 10.1074/jbc.272.17.11302, 9111035

[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=9111035) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=9111035](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=9111035))

[CrossRef](http://dx.doi.org/10.1074/jbc.272.17.11302) (<http://dx.doi.org/10.1074/jbc.272.17.11302>)

[Google Scholar](http://scholar.google.com/scholar_lookup?title=Identification%20of%20a%20region%20of%20interaction%20between%20Escherichia%20coli%20SecA%20and%20SecY%20proteins&author=S.%20Snuyders&author=V.%20Ramamurthy&author=D.%20Oliver&journal=J%20Biol%20Chem&volume=272&pages=11302-11306&publication_year=1997) ([http://scholar.google.com/scholar\\_lookup?title=Identification%20of%20a%20region%20of%20interaction%20between%20Escherichia%20coli%20SecA%20and%20SecY%20proteins&author=S.%20Snuyders&author=V.%20Ramamurthy&author=D.%20Oliver&journal=J%20Biol%20Chem&volume=272&pages=11302-11306&publication\\_year=1997](http://scholar.google.com/scholar_lookup?title=Identification%20of%20a%20region%20of%20interaction%20between%20Escherichia%20coli%20SecA%20and%20SecY%20proteins&author=S.%20Snuyders&author=V.%20Ramamurthy&author=D.%20Oliver&journal=J%20Biol%20Chem&volume=272&pages=11302-11306&publication_year=1997))

30. Ruspantini I, Diociaiuti M, Ippoliti R, *et al.* Immunogold localisation of P-glycoprotein in supported lipid bilayers by transmission electron microscopy and atomic force microscopy. *Histochem J*, 2001, 33: 305–309  
1:CAS:528:DC%2BD3MXnt1SnurY%3D, 10.1023/A:1017933225226, 11563544  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=11563544) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=11563544](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=11563544))  
[CrossRef](http://dx.doi.org/10.1023/A:1017933225226) (<http://dx.doi.org/10.1023/A:1017933225226>)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Immunogold%20localisation%20of%20P-glycoprotein%20in%20supported%20lipid%20bilayers%20by%20transmission%20electron%20microscopy%20and%20atomic%20force%20microscopy&author=I.%20Ruspantini&author=M.%20Diociaiuti&author=R.%20Ippoliti&journal=Histochem%20J&volume=33&pages=305-309&publication_year=2001) ([http://scholar.google.com/scholar\\_lookup?title=Immunogold%20localisation%20of%20P-glycoprotein%20in%20supported%20lipid%20bilayers%20by%20transmission%20electron%20microscopy%20and%20atomic%20force%20microscopy&author=I.%20Ruspantini&author=M.%20Diociaiuti&author=R.%20Ippoliti&journal=Histochem%20J&volume=33&pages=305-309&publication\\_year=2001](http://scholar.google.com/scholar_lookup?title=Immunogold%20localisation%20of%20P-glycoprotein%20in%20supported%20lipid%20bilayers%20by%20transmission%20electron%20microscopy%20and%20atomic%20force%20microscopy&author=I.%20Ruspantini&author=M.%20Diociaiuti&author=R.%20Ippoliti&journal=Histochem%20J&volume=33&pages=305-309&publication_year=2001))
31. van der Wolk J P, de Wit J G, Driessen A J. The catalytic cycle of the *Escherichia coli* SecA ATPase comprises two distinct preprotein translocation events. *Embo J*, 1997, 16: 7297–7304 10.1093/emboj/16.24.7297, 9405359  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=9405359) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=9405359](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=9405359))  
[PubMedCentral](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1170330) (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1170330>)  
[CrossRef](http://dx.doi.org/10.1093/emboj/16.24.7297) (<http://dx.doi.org/10.1093/emboj/16.24.7297>)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=The%20catalytic%20cycle%20of%20the%20Escherichia%20coli%20SecA%20ATPase%20comprises%20two%20distinct%20preprotein%20translocation%20events&author=J.%20P.%20Wolk&author=J.%20G.%20Wit&author=A.%20J.%20Driessen&journal=Embo%20J&volume=16&pages=7297-7304&publication_year=1997) ([http://scholar.google.com/scholar\\_lookup?title=The%20catalytic%20cycle%20of%20the%20Escherichia%20coli%20SecA%20ATPase%20comprises%20two%20distinct%20preprotein%20translocation%20events&author=J.%20P.%20Wolk&author=J.%20G.%20Wit&author=A.%20J.%20Driessen&journal=Embo%20J&volume=16&pages=7297-7304&publication\\_year=1997](http://scholar.google.com/scholar_lookup?title=The%20catalytic%20cycle%20of%20the%20Escherichia%20coli%20SecA%20ATPase%20comprises%20two%20distinct%20preprotein%20translocation%20events&author=J.%20P.%20Wolk&author=J.%20G.%20Wit&author=A.%20J.%20Driessen&journal=Embo%20J&volume=16&pages=7297-7304&publication_year=1997))
32. Ludtke S J, Baldwin P R, Chiu W. EMAN: semiautomated software for high-resolution single-particle reconstructions. *J Struct Biol*, 1999, 128: 82–97  
1:CAS:528:DyaK1MXnvFejsrw%3D, 10.1006/jsbi.1999.4174, 10600563  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=10600563) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=10600563](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=10600563))  
[CrossRef](http://dx.doi.org/10.1006/jsbi.1999.4174) (<http://dx.doi.org/10.1006/jsbi.1999.4174>)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=EMAN%3A%20semiautomated%20software%20for%20high-resolution%20single-particle%20reconstructions&author=S.%20J.%20Ludtke&author=P.%20R.%20Baldwin&author=W.%20Chiu&journal=J%20Struct%20Biol&volume=128&pages=82-97&publication_year=1999) ([http://scholar.google.com/scholar\\_lookup?title=EMAN%3A%20semiautomated%20software%20for%20high-resolution%20single-particle%20reconstructions&author=S.%20J.%20Ludtke&author=P.%20R.%20Baldwin&author=W.%20Chiu&journal=J%20Struct%20Biol&volume=128&pages=82-97&publication\\_year=1999](http://scholar.google.com/scholar_lookup?title=EMAN%3A%20semiautomated%20software%20for%20high-resolution%20single-particle%20reconstructions&author=S.%20J.%20Ludtke&author=P.%20R.%20Baldwin&author=W.%20Chiu&journal=J%20Struct%20Biol&volume=128&pages=82-97&publication_year=1999))
33. Frank J, Radermacher M, Penczek P, *et al.* SPIDER and WEB: processing and visualization of images in 3D electron microscopy and related fields. *J Struct Biol*, 1996, 116: 190–199 1:STN:280:DyaK28zmtF2isw%3D%3D, 10.1006/jsbi.1996.0030, 8742743

**PubMed** ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=8742743](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=8742743))  
**CrossRef** (<http://dx.doi.org/10.1006/jsbi.1996.0030>)  
**Google Scholar** ([http://scholar.google.com/scholar\\_lookup?title=SPIDER%20and%20WEB%3A%20processing%20and%20visualization%20of%20images%20in%203D%20electron%20microscopy%20and%20related%20fields&author=J..%20Frank&author=M..%20Radermacher&author=P..%20Penczek&journal=J%20Struct%20Biol&volume=116&pages=190-199&publication\\_year=1996](http://scholar.google.com/scholar_lookup?title=SPIDER%20and%20WEB%3A%20processing%20and%20visualization%20of%20images%20in%203D%20electron%20microscopy%20and%20related%20fields&author=J..%20Frank&author=M..%20Radermacher&author=P..%20Penczek&journal=J%20Struct%20Biol&volume=116&pages=190-199&publication_year=1996))

34. Frank J. Three-dimensional electron microscopy of macromolecular assemblies, San Diego: Academic Press, 1996

**Google Scholar** ([http://scholar.google.com/scholar\\_lookup?title=Three-dimensional%20electron%20microscopy%20of%20macromolecular%20assemblies&author=J..%20Frank&publication\\_year=1996](http://scholar.google.com/scholar_lookup?title=Three-dimensional%20electron%20microscopy%20of%20macromolecular%20assemblies&author=J..%20Frank&publication_year=1996))

35. Hanada M, Nishiyama K I, Mizushima S, *et al.* Reconstitution of an efficient protein translocation machinery comprising SecA and the three membrane proteins, SecY, SecE, and SecG (p12). J Biol Chem, 1994, 269: 23625–23631 1:CAS:528:DyaK2cXmt1Cnsr%3D, 8089132

**PubMed** ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=8089132](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=8089132))  
**Google Scholar** ([http://scholar.google.com/scholar\\_lookup?title=Reconstitution%20of%20an%20efficient%20protein%20translocation%20omachinery%20comprising%20SecA%20and%20the%20three%20membrane%20proteins%2C%20SecY%2C%20SecE%2C%20and%20SecG%20%28p12%29&author=M..%20Hanada&author=K..%20I..%20Nishiyama&author=S..%20Mizushima&journal=J%20Biol%20Chem&volume=269&pages=23625-23631&publication\\_year=1994](http://scholar.google.com/scholar_lookup?title=Reconstitution%20of%20an%20efficient%20protein%20translocation%20omachinery%20comprising%20SecA%20and%20the%20three%20membrane%20proteins%2C%20SecY%2C%20SecE%2C%20and%20SecG%20%28p12%29&author=M..%20Hanada&author=K..%20I..%20Nishiyama&author=S..%20Mizushima&journal=J%20Biol%20Chem&volume=269&pages=23625-23631&publication_year=1994))

36. Hartl F U, Lecker S, Schiebel E, *et al.* The binding cascade of SecB to SecA to SecY/E mediates preprotein targeting to the *E. coli* plasma membrane. Cell, 1990, 63: 269–279 1:CAS:528:DyaK3cXmtVyisbY%3D, 10.1016/0092-8674(90)90160-G, 2170023

**PubMed** ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=2170023](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=2170023))  
**CrossRef** ([http://dx.doi.org/10.1016/0092-8674\(90\)90160-G](http://dx.doi.org/10.1016/0092-8674(90)90160-G))  
**Google Scholar** ([http://scholar.google.com/scholar\\_lookup?title=The%20binding%20cascade%20of%20SecB%20to%20SecA%20to%20SecY%2FE%20mediates%20preprotein%20targeting%20to%20the%20E.%20coli%20plasma%20membrane&author=F..%20U..%20Hartl&author=S..%20Lecker&author=E..%20Schiebel&journal=Cell&volume=63&pages=269-279&publication\\_year=1990](http://scholar.google.com/scholar_lookup?title=The%20binding%20cascade%20of%20SecB%20to%20SecA%20to%20SecY%2FE%20mediates%20preprotein%20targeting%20to%20the%20E.%20coli%20plasma%20membrane&author=F..%20U..%20Hartl&author=S..%20Lecker&author=E..%20Schiebel&journal=Cell&volume=63&pages=269-279&publication_year=1990))

37. Brundage L, Hendrick J P, Schiebel E, *et al.* The purified *E. coli* integral membrane protein SecY/E is sufficient for reconstitution of SecA-dependent precursor protein translocation. Cell, 1990, 62: 649–657 1:CAS:528:DyaK3cXlsVyrtrw%3D, 10.1016/0092-8674(90)90111-Q, 2167176

**PubMed** ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=2167176](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=2167176))  
**CrossRef** ([http://dx.doi.org/10.1016/0092-8674\(90\)90111-Q](http://dx.doi.org/10.1016/0092-8674(90)90111-Q))  
**Google Scholar** ([http://scholar.google.com/scholar\\_lookup?title=The%20purified%20E.%20coli%20integral%20membrane%20protein%20oSecY%2FE%20is%20sufficient%20for%20reconstitution%20of%20SecA-dependent%20precursor%20protein%20translocation&author=L..%20Brunda](http://scholar.google.com/scholar_lookup?title=The%20purified%20E.%20coli%20integral%20membrane%20protein%20oSecY%2FE%20is%20sufficient%20for%20reconstitution%20of%20SecA-dependent%20precursor%20protein%20translocation&author=L..%20Brunda))

ge&author=J.%20P..%20Hendrick&author=E..%20Schiebel&journal=Cell&volume=62&pages=649-657&publication\_year=1990)

38. Bassilana M, Wickner W. Purified *Escherichia coli* preprotein translocase catalyzes multiple cycles of precursor protein translocation. *Biochemistry*, 1993, 32: 2626–2630 1:CAS:528:DyaK3sXhtF2hsbg%3D, 10.1021/bi00061a021, 8448119  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=8448119) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=8448119)  
[CrossRef](http://dx.doi.org/10.1021/bi00061a021) (http://dx.doi.org/10.1021/bi00061a021)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Purified%20Escherichia%20coli%20preprotein%20translocase%20catalyzes%20multiple%20cycles%20of%20precursor%20protein%20translocation&author=M..%20Bassilana&author=W..%20Wickner&journal=Biochemistry&volume=32&pages=2626-2630&publication_year=1993) (http://scholar.google.com/scholar\_lookup?title=Purified%20Escherichia%20coli%20preprotein%20translocase%20catalyzes%20multiple%20cycles%20of%20precursor%20protein%20translocation&author=M..%20Bassilana&author=W..%20Wickner&journal=Biochemistry&volume=32&pages=2626-2630&publication\_year=1993)
39. Douville K, Price A, Eichler J, *et al.* SecYEG and SecA are the stoichiometric components of preprotein translocase. *J Biol Chem*, 1995, 270: 20106–20111 1:CAS:528:DyaK2MXnvVClS7c%3D, 10.1074/jbc.270.34.20106, 7650029  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=7650029) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=7650029)  
[CrossRef](http://dx.doi.org/10.1074/jbc.270.34.20106) (http://dx.doi.org/10.1074/jbc.270.34.20106)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=SecYEG%20and%20SecA%20are%20the%20stoichiometric%20components%20of%20preprotein%20translocase&author=K..%20Douville&author=A..%20Price&author=J..%20Eichler&journal=J%20Biol%20Chem&volume=270&pages=20106-20111&publication_year=1995) (http://scholar.google.com/scholar\_lookup?title=SecYEG%20and%20SecA%20are%20the%20stoichiometric%20components%20of%20preprotein%20translocase&author=K..%20Douville&author=A..%20Price&author=J..%20Eichler&journal=J%20Biol%20Chem&volume=270&pages=20106-20111&publication\_year=1995)
40. Driessen A J, Nouwen N. Protein translocation across the bacterial cytoplasmic membrane. *Annu Rev Biochem*, 2008, 77: 643–667 1:CAS:528:DC%2BD1cXos1eku7w%3D, 10.1146/annurev.biochem.77.061606.160747, 18078384  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=18078384) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=18078384)  
[CrossRef](http://dx.doi.org/10.1146/annurev.biochem.77.061606.160747) (http://dx.doi.org/10.1146/annurev.biochem.77.061606.160747)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Protein%20translocation%20across%20the%20bacterial%20cytoplasmic%20membrane&author=A.%20J..%20Driessen&author=N..%20Nouwen&journal=Annu%20Rev%20Biochem&volume=77&pages=643-667&publication_year=2008) (http://scholar.google.com/scholar\_lookup?title=Protein%20translocation%20across%20the%20bacterial%20cytoplasmic%20membrane&author=A.%20J..%20Driessen&author=N..%20Nouwen&journal=Annu%20Rev%20Biochem&volume=77&pages=643-667&publication\_year=2008)
41. Van den Berg B, Clemons W M Jr, Collinson I, *et al.* X-ray structure of a protein-conducting channel. *Nature*, 2004, 427: 36–44 10.1038/nature02218, 14661030  
[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=14661030) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\_uids=14661030)  
[CrossRef](http://dx.doi.org/10.1038/nature02218) (http://dx.doi.org/10.1038/nature02218)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=X-ray%20structure%20of%20a%20protein-conducting%20channel&author=B..%20Berg&author=W.%20M..%20Clemons&author=I..%20Collinson&journal=Nature&volume=427&pages=36-44&publication_year=2004) (http://scholar.google.com/scholar\_lookup?title=X-ray%20structure%20of%20a%20protein-conducting%20channel&author=B..%20Berg&author=W.%20M..%20Clemons&author=I..%20Collinson&journal=Nature&volume=427&pages=36-44&publication\_year=2004)
42. Duong F. Binding, activation and dissociation of the dimeric SecA ATPase at the dimeric SecYEG translocase. *Embo J*, 2003, 22: 4375–4384 1:CAS:528:DC%2BD3sXmvVWktLg%3D, 10.1093/emboj/cdg418, 12941690

[PubMed](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=12941690) ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list\\_uids=12941690](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Abstract&list_uids=12941690))  
[PubMedCentral](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC202361) (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC202361>)  
[CrossRef](http://dx.doi.org/10.1093/emboj/cdg418) (<http://dx.doi.org/10.1093/emboj/cdg418>)  
[Google Scholar](http://scholar.google.com/scholar_lookup?title=Binding%2C%20activation%20and%20dissociation%20of%20the%20dimeric%20SecA%20ATPase%20at%20the%20dimeric%20SecYEG%20translocation&author=F..%20Duong&journal=Embo%20J&volume=22&pages=4375-4384&publication_year=2003) ([http://scholar.google.com/scholar\\_lookup?title=Binding%2C%20activation%20and%20dissociation%20of%20the%20dimeric%20SecA%20ATPase%20at%20the%20dimeric%20SecYEG%20translocation&author=F..%20Duong&journal=Embo%20J&volume=22&pages=4375-4384&publication\\_year=2003](http://scholar.google.com/scholar_lookup?title=Binding%2C%20activation%20and%20dissociation%20of%20the%20dimeric%20SecA%20ATPase%20at%20the%20dimeric%20SecYEG%20translocation&author=F..%20Duong&journal=Embo%20J&volume=22&pages=4375-4384&publication_year=2003))

## Copyright information

© Science China Press and Springer-Verlag Berlin Heidelberg 2010

## About this article

- Publisher Name Science China Press
- Print ISSN 1674-7305
- Online ISSN 1869-1889
- [About this journal](#)
- [Reprints and Permissions](#)

## Personalised recommendations

1. [Cryo-EM structures of MERS-CoV and SARS-CoV spike glycoproteins reveal the dynamic receptor binding domains](#)  
Yuan, Yuan... Gao, George F.  
*Nature Communications* (2017)
2. [Crystal structure of the ATPase-C domain of the chromatin remodeller Fun30 from \*Saccharomyces cerevisiae\*](#)  
Liu, Lan... Jiang, Tao  
*Acta Crystallographica Section F Structural Biology Communications* (2017)
3. [High-resolution cryo-EM structure of the proteasome in complex with ADP-AlFx](#)  
Ding, Zhanyu... Cong, Yao  
*Cell Research* (2017)

Powered by: **Recommended** 

**SPRINGER NATURE**

© 2017 Springer International Publishing AG. Part of [Springer Nature](#).

Not logged in Tsinghua University (2000400553) - 5102 SpringerLink China OAC National Consortium (3000202650) - 7755 SpringerLink China Consortium (3000521924) - 9665 SLCC National Consortium Full Collection (985) (3000747636) - 14581 SpringerProtocols China National Consortium (3001312038) - SpringerLink China eBook Consortium (Higher Education) - Full Collection (3002152075) - China SBA Consortium 2014 (3991455513) - SLCC National Consortium – Full Collection (985) 2015-2017 (3991456307) 101.5.82.143