



Universiteit
Leiden
The Netherlands

Force generation in dividing *E. coli* cells: A handles-on approach using optical tweezers

Verhoeven, G.S.

Citation

Verhoeven, G. S. (2008, December 2). *Force generation in dividing *E. coli* cells: A handles-on approach using optical tweezers*. Retrieved from <https://hdl.handle.net/1887/13301>

Version: Corrected Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/13301>

Note: To cite this publication please use the final published version (if applicable).

Bibliography

- Aarsman, M. E., A. Piette, et al. (2005). "Maturation of the Escherichia coli divisome occurs in two steps." *Mol Microbiol* **55**(6): 1631-45.
- Addinall, S. G. and J. Lutkenhaus (1996). "FtsZ-spirals and -arcs determine the shape of the invaginating septa in some mutants of Escherichia coli." *Mol Microbiol* **22**(2): 231-7.
- Akama, H., T. Matsuura, et al. (2004). "Crystal structure of the membrane fusion protein, MexA, of the multidrug transporter in Pseudomonas aeruginosa." *J Biol Chem* **279**(25): 25939-42.
- Alberts, B. (2002). *Molecular Biology of the Cell*, Garland Publishing, Incorporated.
- Alexeeva, S. A., G. S. Verhoeven, et al.
- Amann, E., B. Ochs, et al. (1988). "Tightly regulated tac promoter vectors useful for the expression of unfused and fused proteins in Escherichia coli." *Gene* **69**(2): 301-15.
- Andrews, S. S. and A. P. Arkin (2007). "A mechanical explanation for cytoskeletal rings and helices in bacteria." *Biophys J* **93**(6): 1872-84.
- Arjara, G. (2007). Refolding a beta-barrel membrane protein. Pasadena, California Institute of Technology.
- Arnoldi, M., M. Fritz, et al. (2000). "Bacterial turgor pressure can be measured by atomic force microscopy." *Phys Rev E Stat Phys Plasmas Fluids Relat Interdiscip Topics* **62**(1 Pt B): 1034-44.
- Ashkin, A. (1970). "Acceleration and Trapping of Particles by Radiation Pressure." *Physical Review Letters* **24**(4): 156-159.
- Ashkin, A., J. M. Dziedzic, et al. (1986). "Observation of a single-beam gradient force optical trap for dielectric particles." *Optics Letters* **11**(5): 288-290.
- Ashkin, A., J. M. Dziedzic, et al. (1987). "Optical trapping and manipulation of single cells using infrared laser beams." *Nature* **330**(6150): 769-771.
- Atakhorrami, M., K. M. Addas, et al. (2008). "Twin optical traps for two-particle cross-correlation measurements: eliminating cross-talk." *Rev Sci Instrum* **79**(4): 043103.

Bibliography

- Ayano, S., Y. Wakamoto, et al. (2006). "Quantitative measurement of damage caused by 1064-nm wavelength optical trapping of Escherichia coli cells using on-chip single cell cultivation system." *Biochem Biophys Res Commun* **350**(3): 678-84.
- Baker, K. A., R. E. Dutch, et al. (1999). "Structural basis for paramyxovirus-mediated membrane fusion." *Mol Cell* **3**(3): 309-19.
- Beckett, D., E. Kovaleva, et al. (1999). "A minimal peptide substrate in biotin holoenzyme synthetase-catalyzed biotinylation." *Protein Sci* **8**(4): 921-9.
- Bell, G. I. (1978). "Models for the specific adhesion of cells to cells." *Science* **200**(4342): 618-27.
- Benhar, I. (2001). "Biotechnological applications of phage and cell display." *Biotechnol Adv* **19**(1): 1-33.
- Bernhardt, T. G. and P. A. de Boer (2003). "The Escherichia coli amidase AmiC is a periplasmic septal ring component exported via the twin-arginine transport pathway." *Mol Microbiol* **48**(5): 1171-82.
- Bernhardt, T. G. and P. A. de Boer (2004). "Screening for synthetic lethal mutants in Escherichia coli and identification of EnvC (YibP) as a periplasmic septal ring factor with murein hydrolase activity." *Mol Microbiol* **52**(5): 1255-69.
- Bernstein, H. D. (2007). "Are bacterial 'autotransporters' really transporters?" *Trends Microbiol* **15**(10): 441-7.
- Bessette, P. H., J. J. Rice, et al. (2004). "Rapid isolation of high-affinity protein binding peptides using bacterial display." *Protein Eng Des Sel* **17**(10): 731-9.
- Bi, E. F. and J. Lutkenhaus (1991). "FtsZ ring structure associated with division in Escherichia coli." *Nature* **354**(6349): 161-4.
- Bonsor, D. A., I. Grishkovskaya, et al. (2007). "Molecular mimicry enables competitive recruitment by a natively disordered protein." *J Am Chem Soc* **129**(15): 4800-7.
- Bos, M. P., V. Robert, et al. (2007). "Biogenesis of the gram-negative bacterial outer membrane." *Annu Rev Microbiol* **61**: 191-214.
- Bos, M. P., B. Tefsen, et al. (2004). "Identification of an outer membrane protein required for the transport of lipopolysaccharide to the bacterial cell surface." *Proc Natl*

Bibliography

- Acad Sci U S A **101**(25): 9417-22.
- Boulbitch, A. (2000). "Deformation of the envelope of a spherical gram-negative bacterium during the atomic force microscopic measurements." J Electron Microsc (Tokyo) **49**(3): 459-62.
- Boulbitch, A., B. Quinn, et al. (2000). "Elasticity of the rod-shaped gram-negative eubacteria." Phys Rev Lett **85**(24): 5246-9.
- Bradburne, J. A., P. Godfrey, et al. (1993). "In vivo labeling of Escherichia coli cell envelope proteins with N- hydroxysuccinimide esters of biotin." Applied and Environmental Microbiology **59**(3): 663-668.
- Bramhill, D. (1997). "Bacterial cell division." Annu Rev Cell Dev Biol **13**: 395-424.
- Bramhill, D. and C. M. Thompson (1994). "GTP-dependent polymerization of Escherichia coli FtsZ protein to form tubules." Proc Natl Acad Sci U S A **91**(13): 5813-7.
- Brass, J. M., C. F. Higgins, et al. (1986). "Lateral diffusion of proteins in the periplasm of Escherichia coli." J Bacteriol **165**(3): 787-95.
- Buddelmeijer, N. and J. Beckwith (2004). "A complex of the Escherichia coli cell division proteins FtsL, FtsB and FtsQ forms independently of its localization to the septal region." Mol Microbiol **52**(5): 1315-27.
- Burdett, I. D. and R. G. Murray (1974). "Septum formation in Escherichia coli: characterization of septal structure and the effects of antibiotics on cell division." J Bacteriol **119**(1): 303-24.
- Bustamante, C., S. B. Smith, et al. (2000). "Single-molecule studies of DNA mechanics." Curr Opin Struct Biol **10**(3): 279-85.
- Cabean, M. T. and C. Jacobs-Wagner (2005). "Bacterial cell shape." Nat Rev Microbiol **3**(8): 601-10.
- Cabean, M. T. and C. Jacobs-Wagner (2007). "Skin and bones: the bacterial cytoskeleton, cell wall, and cell morphogenesis." J Cell Biol **179**(3): 381-7.
- Carson, M. J., J. Barondess, et al. (1991). "The FtsQ protein of Escherichia coli: membrane topology, abundance, and cell division phenotypes due to overproduction and insertion mutations." J Bacteriol **173**(7): 2187-95.

Bibliography

- Casadaban, M. J. and S. N. Cohen (1980). "Analysis of gene control signals by DNA fusion and cloning in Escherichia coli." J Mol Biol **138**(2): 179-207.
- Cascales, E., A. Bernadac, et al. (2002). "Pal lipoprotein of Escherichia coli plays a major role in outer membrane integrity." J Bacteriol **184**(3): 754-9.
- Cascales, E. and R. Lloubes (2004). "Deletion analyses of the peptidoglycan-associated lipoprotein Pal reveals three independent binding sequences including a TolA box." Mol Microbiol **51**(3): 873-85.
- Cayley, D. S., H. J. Guttman, et al. (2000). "Biophysical characterization of changes in amounts and activity of Escherichia coli cell and compartment water and turgor pressure in response to osmotic stress." Biophys J **78**(4): 1748-64.
- Cecconi, C., E. A. Shank, et al. (2008). "Protein-DNA chimeras for single molecule mechanical folding studies with the optical tweezers." Eur Biophys J **37**(6): 729-38.
- Chapman-Smith, A. and J. E. Cronan, Jr. (1999). "The enzymatic biotinylation of proteins: a post-translational modification of exceptional specificity." Trends Biochem Sci **24**(9): 359-63.
- Chaudhuri, B. N., J. Ko, et al. (1999). "Structure of D-allose binding protein from Escherichia coli bound to D-allose at 1.8 Å resolution." J Mol Biol **286**(5): 1519-31.
- Chen, J. C., P. H. Viollier, et al. (2005). "A membrane metalloprotease participates in the sequential degradation of a Caulobacter polarity determinant." Mol Microbiol **55**(4): 1085-103.
- Chen, R., W. Schmidmayr, et al. (1980). "Primary structure of major outer membrane protein II (ompA protein) of Escherichia coli K-12." Proc Natl Acad Sci U S A **77**(8): 4592-6.
- Clavel, T., P. Germon, et al. (1998). "TolB protein of Escherichia coli K-12 interacts with the outer membrane peptidoglycan-associated proteins Pal, Lpp and OmpA." Mol Microbiol **29**(1): 359-67.
- Cole, S. T., U. Chen-Schmeisser, et al. (1983). "Apparent bacteriophage-binding region of an Escherichia coli K-12 outer membrane protein." J Bacteriol **153**(2): 581-7.

Bibliography

- Collins, R. F., K. Beis, et al. (2007). "The 3D structure of a periplasm-spanning platform required for assembly of group 1 capsular polysaccharides in Escherichia coli." *Proc Natl Acad Sci U S A* **104**(7): 2390-5.
- Cormack, B. P., R. H. Valdivia, et al. (1996). "FACS-optimized mutants of the green fluorescent protein (GFP)." *Gene* **173**(1 Spec No): 33-8.
- Costa, T., R. Priyadarshini, et al. (2008). "Localization of PBP3 in Caulobacter crescentus is highly dynamic and largely relies on its functional transpeptidase domain." *Mol Microbiol*.
- Costanzo, A. and S. E. Ades (2006). "Growth phase-dependent regulation of the extracytoplasmic stress factor, sigmaE, by guanosine 3',5'-bispyrophosphate (ppGpp)." *J Bacteriol* **188**(13): 4627-34.
- Dai, J. and M. P. Sheetz (1995). "Mechanical properties of neuronal growth cone membranes studied by tether formation with laser optical tweezers." *Biophys J* **68**(3): 988-96.
- Daniel, R. A., E. J. Harry, et al. (2000). "Role of penicillin-binding protein PBP 2B in assembly and functioning of the division machinery of *Bacillus subtilis*." *Mol Microbiol* **35**(2): 299-311.
- Davison, M. T. and P. B. Garland (1983). "Immunochemical demonstration of zonal growth of the cell envelope of *Escherichia coli*." *European Journal of Biochemistry* **130**(3): 589-597.
- de Boer, P. A., R. E. Crossley, et al. (1989). "A division inhibitor and a topological specificity factor coded for by the minicell locus determine proper placement of the division septum in *E. coli*." *Cell* **56**(4): 641-9.
- de Jonge, B. L., F. B. Wientjes, et al. (1989). "Peptidoglycan synthesis during the cell cycle of *Escherichia coli*: composition and mode of insertion." *J Bacteriol* **171**(11): 5783-94.
- de Pedro, M. A., C. G. Grunfelder, et al. (2004). "Restricted Mobility of Cell Surface Proteins in the Polar Regions of *Escherichia coli*." *J Bacteriol* **186**(9): 2594-602.
- de Pedro, M. A., J. C. Quintela, et al. (1997). "Murein segregation in *Escherichia coli*." *J*

Bibliography

- Bacteriol **179**(9): 2823-34.
- Deich, J., E. M. Judd, et al. (2004). "Visualization of the movement of single histidine kinase molecules in live Caulobacter cells." Proc Natl Acad Sci U S A **101**(45): 15921-6.
- Demchick, P. and A. L. Koch (1996). "The permeability of the wall fabric of Escherichia coli and Bacillus subtilis." J Bacteriol **178**(3): 768-73.
- Den Blaauwen, T., M. E. Aarsman, et al. (2003). "Penicillin-binding protein PBP2 of Escherichia coli localizes preferentially in the lateral wall and at mid-cell in comparison with the old cell pole." Mol Microbiol **47**(2): 539-47.
- den Blaauwen, T., M. A. de Pedro, et al. (2008). "Morphogenesis of rod-shaped sacculi." FEMS Microbiol Rev **32**(2): 321-44.
- Denome, S. A., P. K. Elf, et al. (1999). "Escherichia coli mutants lacking all possible combinations of eight penicillin binding proteins: viability, characteristics, and implications for peptidoglycan synthesis." J Bacteriol **181**(13): 3981-93.
- Deroo, S., A. Fischer, et al. (2008). "Non-immunized natural human heavy chain CDR3 repertoires allow the isolation of high affinity peptides mimicking a human influenza hemagglutinin epitope." Molecular Immunology **45**(5): 1366-1373.
- Dijkstra, A. J. and W. Keck (1996). "Peptidoglycan as a barrier to transenvelope transport." J Bacteriol **178**(19): 5555-62.
- Dinh, T., I. T. Paulsen, et al. (1994). "A family of extracytoplasmic proteins that allow transport of large molecules across the outer membranes of gram-negative bacteria." J Bacteriol **176**(13): 3825-31.
- Dogterom, M. and B. Yurke (1997). "Measurement of the force-velocity relation for growing microtubules." Science **278**(5339): 856-60.
- Drew, D., M. Lerch, et al. (2006). "Optimization of membrane protein overexpression and purification using GFP fusions." Nat Methods **3**(4): 303-13.
- Eggert, U. S., T. J. Mitchison, et al. (2006). "Animal cytokinesis: from parts list to mechanisms." Annu Rev Biochem **75**: 543-66.
- Eisner, G., H. G. Koch, et al. (2003). "Ligand crowding at a nascent signal sequence." J Cell Biol **163**(1): 35-44.

Bibliography

- Elkins, C. A. and H. Nikaido (2003). "Chimeric analysis of AcrA function reveals the importance of its C-terminal domain in its interaction with the AcrB multidrug efflux pump." *J Bacteriol* **185**(18): 5349-56.
- Erickson, H. P. (1995). "FtsZ, a prokaryotic homolog of tubulin?" *Cell* **80**(3): 367-70.
- Erickson, H. P. (1997). "FtsZ, a tubulin homologue in prokaryote cell division." *Trends Cell Biol* **7**(9): 362-7.
- Ericsson, M., D. Hanstorp, et al. (2000). "Sorting out bacterial viability with optical tweezers." *J Bacteriol* **182**(19): 5551-5.
- Errington, J., R. A. Daniel, et al. (2003). "Cytokinesis in bacteria." *Microbiol Mol Biol Rev* **67**(1): 52-65, table of contents.
- Evans, E. and K. Ritchie (1997). "Dynamic strength of molecular adhesion bonds." *Biophys J* **72**(4): 1541-55.
- Fallman, E., S. Schedin, et al. (2004). "Optical tweezers based force measurement system for quantitating binding interactions: system design and application for the study of bacterial adhesion." *Biosens Bioelectron* **19**(11): 1429-37.
- Fishov, I., A. Zaritsky, et al. (1995). "On microbial states of growth." *Mol Microbiol* **15**(5): 789-94.
- Freudl, R. (1989). "Insertion of peptides into cell-surface-exposed areas of the Escherichia coli OmpA protein does not interfere with export and membrane assembly." *Gene* **82**(2): 229-36.
- Freudl, R., S. MacIntyre, et al. (1986). "Cell surface exposure of the outer membrane protein OmpA of Escherichia coli K-12." *J Mol Biol* **188**(3): 491-4.
- Fukushima, T., A. Afkham, et al. (2006). "A new D,L-endopeptidase gene product, YojL (renamed CwlS), plays a role in cell separation with LytE and LytF in *Bacillus subtilis*." *J Bacteriol* **188**(15): 5541-50.
- Gabay, J. and K. Yasunaka (1980). "Interaction of the lamB protein with the peptidoglycan layer in Escherichia coli K12." *Eur J Biochem* **104**(1): 13-8.
- Gelles, J., B. J. Schnapp, et al. (1988). "Tracking kinesin-driven movements with nanometre-scale precision." *Nature* **331**(6155): 450-3.

Bibliography

- Gentle, I. E., L. Burri, et al. (2005). "Molecular architecture and function of the Omp85 family of proteins." *Mol Microbiol* **58**(5): 1216-25.
- Gerding, M. A., Y. Ogata, et al. (2007). "The trans-envelope Tol-Pal complex is part of the cell division machinery and required for proper outer-membrane invagination during cell constriction in *E. coli*." *Mol Microbiol* **63**(4): 1008-25.
- Ghosh, A. S. and K. D. Young (2005). "Helical disposition of proteins and lipopolysaccharide in the outer membrane of *Escherichia coli*." *J Bacteriol* **187**(6): 1913-22.
- Ghosh, B. and A. Sain (2008). "Origin of contractile force during cell division of bacteria." *Phys Rev Lett*.
- Gibbs, K. A., D. D. Isaac, et al. (2004). "Complex spatial distribution and dynamics of an abundant *Escherichia coli* outer membrane protein, LamB." *Mol Microbiol* **53**(6): 1771-83.
- Giebel, L. B., R. T. Cass, et al. (1995). "Screening of cyclic peptide phage libraries identifies ligands that bind streptavidin with high affinities." *Biochemistry* **34**(47): 15430-5.
- Gittes, F. and C. F. Schmidt (1998). "Signals and noise in micromechanical measurements." *Methods Cell Biol* **55**: 129-56.
- Goehring, N. W. and J. Beckwith (2005). "Diverse paths to midcell: assembly of the bacterial cell division machinery." *Curr Biol* **15**(13): R514-26.
- Goldstein, R. E. and A. Goriely (2006). "Dynamic buckling of morphoelastic filaments." *Phys Rev E Stat Nonlin Soft Matter Phys* **74**(1 Pt 1): 010901.
- Grange, W., S. Husale, et al. (2002). "Optical tweezers system measuring the change in light momentum flux." *Review of Scientific Instruments* **73**(6): 2308.
- Grishchuk, E. L., M. I. Molodtsov, et al. (2005). "Force production by disassembling microtubules." *Nature* **438**(7066): 384-8.
- Guex, N. and M. C. Peitsch (1997). "SWISS-MODEL and the Swiss-PdbViewer: an environment for comparative protein modeling." *Electrophoresis* **18**(15): 2714-23.
- Gumpert, J., E. Schuhmann, et al. (1971). "[Ultrastructure of stable L forms of *Escherichia coli* B and W 1655F]." *Z Allg Mikrobiol* **11**(1): 19-33.

Bibliography

- Hahn, J., B. Maier, et al. (2005). "Transformation proteins and DNA uptake localize to the cell poles in *Bacillus subtilis*." *Cell* **122**(1): 59-71.
- Harvey, B. R., G. Georgiou, et al. (2004). "Anchored periplasmic expression, a versatile technology for the isolation of high-affinity antibodies from *Escherichia coli*-expressed libraries." *Proc Natl Acad Sci U S A* **101**(25): 9193-8.
- Hasselblatt, H., R. Kurzbauer, et al. (2007). "Regulation of the sigmaE stress response by DegS: how the PDZ domain keeps the protease inactive in the resting state and allows integration of different OMP-derived stress signals upon folding stress." *Genes Dev* **21**(20): 2659-70.
- Heidrich, C., M. F. Templin, et al. (2001). "Involvement of N-acetylmuramyl-L-alanine amidases in cell separation and antibiotic-induced autolysis of *Escherichia coli*." *Mol Microbiol* **41**(1): 167-78.
- Heidrich, C., A. Ursinus, et al. (2002). "Effects of multiple deletions of murein hydrolases on viability, septum cleavage, and sensitivity to large toxic molecules in *Escherichia coli*." *J Bacteriol* **184**(22): 6093-9.
- Henning, U., S. T. Cole, et al. (1983). "Gene fusions using the *ompA* gene coding for a major outer-membrane protein of *Escherichia coli* K12." *Eur J Biochem* **136**(2): 233-40.
- Henning, U., B. Hohn, et al. (1973). "Cell envelope and shape of *Escherichia coli* K12. The ghost membrane." *Eur J Biochem* **39**(1): 27-36.
- Higgins, M. K., E. Bokma, et al. (2004). "Structure of the periplasmic component of a bacterial drug efflux pump." *Proc Natl Acad Sci U S A* **101**(27): 9994-9.
- Hirota, Y., A. Ryter, et al. (1968). "Thermosensitive mutants of *E. coli* affected in the processes of DNA synthesis and cellular division." *Cold Spring Harb Symp Quant Biol* **33**: 677-93.
- Hobot, J. A., E. Carlemalm, et al. (1984). "Periplasmic gel: new concept resulting from the reinvestigation of bacterial cell envelope ultrastructure by new methods." *J Bacteriol* **160**(1): 143-52.
- Holtje, J. V. and C. Heidrich (2001). "Enzymology of elongation and constriction of the

Bibliography

- murein sacculus of Escherichia coli." Biochimie **83**(1): 103-8.
- Horger, I., E. Velasco, et al. (2008). "Langevin computer simulations of bacterial protein filaments and the force-generating mechanism during cell division." Phys Rev E Stat Nonlin Soft Matter Phys **77**(1 Pt 1): 011902.
- Howard-Flanders, P., E. Simson, et al. (1964). "A Locus That Controls Filament Formation and Sensitivity to Radiation in Escherichia Coli K-12." Genetics **49**: 237-46.
- Howarth, M., K. Takao, et al. (2005). "Targeting quantum dots to surface proteins in living cells with biotin ligase." Proc Natl Acad Sci U S A **102**(21): 7583-8.
- Howarth, M. and A. Y. Ting (2008). "Imaging proteins in live mammalian cells with biotin ligase and monovalent streptavidin." Nat Protoc **3**(3): 534-45.
- Jain, S. and M. B. Goldberg (2007). "Requirement for YaeT in the outer membrane assembly of autotransporter proteins." J Bacteriol **189**(14): 5393-8.
- Jain, S., P. van Ulsen, et al. (2006). "Polar localization of the autotransporter family of large bacterial virulence proteins." J Bacteriol **188**(13): 4841-50.
- Janson, M. E. and M. Dogterom (2004). "Scaling of microtubule force-velocity curves obtained at different tubulin concentrations." Phys Rev Lett **92**(24): 248101.
- Jass, J., S. Schedin, et al. (2004). "Physical properties of Escherichia coli P pili measured by optical tweezers." Biophys J **87**(6): 4271-83.
- Jauffred, L., T. H. Callisen, et al. (2007). "Visco-elastic membrane tethers extracted from Escherichia coli by optical tweezers." Biophys J **93**(11): 4068-75.
- Johnson, J. M. and G. M. Church (1999). "Alignment and structure prediction of divergent protein families: periplasmic and outer membrane proteins of bacterial efflux pumps." J Mol Biol **287**(3): 695-715.
- Jones, L. J., R. Carballido-Lopez, et al. (2001). "Control of cell shape in bacteria: helical, actin-like filaments in *Bacillus subtilis*." Cell **104**(6): 913-22.
- Joseleau-Petit, D., J. C. Liebart, et al. (2007). "Unstable Escherichia coli L forms revisited: growth requires peptidoglycan synthesis." J Bacteriol **189**(18): 6512-20.
- Judd, E. M., L. R. Comolli, et al. (2005). "Distinct constrictive processes, separated in time and space, divide *caulobacter* inner and outer membranes." J Bacteriol **187**(20):

Bibliography

- 6874-82.
- Kerssemakers, J. W., E. L. Munteanu, et al. (2006). "Assembly dynamics of microtubules at molecular resolution." *Nature* **442**(7103): 709-12.
- Kerssemakers, J. W. J., M. E. Janson, et al. (2003). "Optical trap setup for measuring microtubule pushing forces." *Applied Physics Letters* **83**(21): 4441-4443.
- Kim, C., S. Song, et al. (1997). "The D-allose operon of Escherichia coli K-12." *J Bacteriol* **179**(24): 7631-7.
- Kim, S. Y., Z. Gitai, et al. (2006). "Single molecules of the bacterial actin MreB undergo directed treadmilling motion in Caulobacter crescentus." *Proc Natl Acad Sci U S A* **103**(29): 10929-34.
- Kleinschmidt, J. H. (2006). "Folding kinetics of the outer membrane proteins OmpA and FomA into phospholipid bilayers." *Chem Phys Lipids* **141**(1-2): 30-47.
- Koch, A. L. (1988). "Biophysics of bacterial walls viewed as stress-bearing fabric." *Microbiol Rev* **52**(3): 337-53.
- Koch, A. L. (1998). "The biophysics of the gram-negative periplasmic space." *Crit Rev Microbiol* **24**(1): 23-59.
- Koch, A. L. and M. F. Pinette (1987). "Nephelometric determination of turgor pressure in growing gram-negative bacteria." *J Bacteriol* **169**(8): 3654-63.
- Koch, A. L. and S. Woeste (1992). "Elasticity of the sacculus of Escherichia coli." *J Bacteriol* **174**(14): 4811-9.
- Koebnik, R. (1999). "Structural and functional roles of the surface-exposed loops of the beta-barrel membrane protein OmpA from Escherichia coli." *J Bacteriol* **181**(12): 3688-94.
- Koebnik, R., K. P. Locher, et al. (2000). "Structure and function of bacterial outer membrane proteins: barrels in a nutshell." *Mol Microbiol* **37**(2): 239-53.
- Koppelman, C. M., M. E. Aarsman, et al. (2004). "R174 of Escherichia coli FtsZ is involved in membrane interaction and protofilament bundling, and is essential for cell division." *Mol Microbiol* **51**(3): 645-57.
- Koster, G., A. Cacciuto, et al. (2005). "Force barriers for membrane tube formation." *Phys*

Bibliography

- Rev Lett **94**(6): 068101.
- Koster, G., M. VanDuijn, et al. (2003). "Membrane tube formation from giant vesicles by dynamic association of motor proteins." Proc Natl Acad Sci U S A **100**(26): 15583-8.
- Laan, L., J. Husson, et al. (2008). "Force-generation and dynamic instability of microtubule bundles." Proc Natl Acad Sci U S A **105**(26): 8920-5.
- Lan, G., A. Djakovic, et al. (2008). "Polymerization and bundling kinetics of FtsZ filaments." Biophys J **95**(8): 4045-56.
- Lan, G., C. W. Wolgemuth, et al. (2007). "Z-ring force and cell shape during division in rod-like bacteria." Proc Natl Acad Sci U S A **104**(41): 16110-5.
- Leake, M. C., J. H. Chandler, et al. (2006). "Stoichiometry and turnover in single, functioning membrane protein complexes." Nature **443**(7109): 355-8.
- Lee, S. Y., J. H. Choi, et al. (2003). "Microbial cell-surface display." Trends Biotechnol **21**(1): 45-52.
- Li, Z., M. J. Trimble, et al. (2007). "The structure of FtsZ filaments in vivo suggests a force-generating role in cell division." Embo J **26**(22): 4694-708.
- Lu, C., M. Reedy, et al. (2000). "Straight and curved conformations of FtsZ are regulated by GTP hydrolysis." J Bacteriol **182**(1): 164-70.
- Lutz, R. and H. Bujard (1997). "Independent and tight regulation of transcriptional units in Escherichia coli via the LacR/O, the TetR/O and AraC/I1-I2 regulatory elements." Nucleic Acids Res **25**(6): 1203-10.
- Ma, X., D. W. Ehrhardt, et al. (1996). "Colocalization of cell division proteins FtsZ and FtsA to cytoskeletal structures in living Escherichia coli cells by using green fluorescent protein." Proc Natl Acad Sci U S A **93**(23): 12998-3003.
- Magnusson, U., B. N. Chaudhuri, et al. (2002). "Hinge-bending motion of D-allose-binding protein from Escherichia coli: three open conformations." J Biol Chem **277**(16): 14077-84.
- Maier, B., I. Chen, et al. (2004). "DNA transport into Bacillus subtilis requires proton motive force to generate large molecular forces." Nat Struct Mol Biol **11**(7): 643-9.

Bibliography

- Malamy, M. H. and B. L. Horecker (1964). "Release of Alkaline Phosphatase from Cells of Escherichia Coli Upon Lysozyme Spheroplast Formation." *Biochemistry* **3**: 1889-93.
- Manting, E. H., C. van der Does, et al. (1997). "In vivo cross-linking of the SecA and SecY subunits of the Escherichia coli preprotein translocase." *J Bacteriol* **179**(18): 5699-704.
- Matias, V. R., A. Al-Amoudi, et al. (2003). "Cryo-transmission electron microscopy of frozen-hydrated sections of Escherichia coli and Pseudomonas aeruginosa." *J Bacteriol* **185**(20): 6112-8.
- Mendelson, N. H., J. E. Sarlls, et al. (2000). "Chiral self-propulsion of growing bacterial macrofibers on a solid surface." *Phys Rev Lett* **84**(7): 1627-30.
- Mendelson, N. H. and J. J. Thwaites (1989). "Cell wall mechanical properties as measured with bacterial thread made from *Bacillus subtilis*." *J Bacteriol* **171**(2): 1055-62.
- Mikolosko, J., K. Bobyk, et al. (2006). "Conformational flexibility in the multidrug efflux system protein AcrA." *Structure* **14**(3): 577-87.
- Mills, J. P., L. Qie, et al. (2004). "Nonlinear elastic and viscoelastic deformation of the human red blood cell with optical tweezers." *Mech Chem Biosyst* **1**(3): 169-80.
- Mingorance, J., M. Tadros, et al. (2005). "Visualization of single Escherichia coli FtsZ filament dynamics with atomic force microscopy." *J Biol Chem* **280**(21): 20909-14.
- Mitra, K., J. Frank, et al. (2006). "Co- and post-translational translocation through the protein-conducting channel: analogous mechanisms at work?" *Nat Struct Mol Biol* **13**(11): 957-64.
- Moffitt, J. R., Y. R. Chemla, et al. (2008). "Recent advances in optical tweezers." *Annu Rev Biochem* **77**: 205-28.
- Monod, J., G. Cohen-Bazire, et al. (1951). "Sur la biosynthese de la beta-galactosidase (lactase) chez Escherichia coli; la specificite de l'induction." *Biochim Biophys Acta* **7**(4): 585-99.
- Mukherjee, A. and J. Lutkenhaus (1994). "Guanine nucleotide-dependent assembly of FtsZ into filaments." *J Bacteriol* **176**(9): 2754-8.

Bibliography

- Mukherjee, A., C. Saez, et al. (2001). "Assembly of an FtsZ mutant deficient in GTPase activity has implications for FtsZ assembly and the role of the Z ring in cell division." *J Bacteriol* **183**(24): 7190-7.
- Mullineaux, C. W., A. Nenninger, et al. (2006). "Diffusion of green fluorescent protein in three cell environments in Escherichia coli." *J Bacteriol* **188**(10): 3442-8.
- Murase, K., T. Fujiwara, et al. (2004). "Ultrafine membrane compartments for molecular diffusion as revealed by single molecule techniques." *Biophys J* **86**(6): 4075-93.
- Neidhardt, F. C., P. L. Bloch, et al. (1974). "Culture medium for enterobacteria." *J Bacteriol* **119**(3): 736-47.
- Neu, H. C. and L. A. Heppel (1964). "The Release of Ribonuclease into the Medium When Escherichia Coli Cells Are Converted to Speroplasts." *J Biol Chem* **239**: 3893-900.
- Neuert, G., C. Albrecht, et al. (2006). "Dynamic force spectroscopy of the digoxigenin-antibody complex." *FEBS Lett* **580**(2): 505-9.
- Neuman, K. C., E. H. Chadd, et al. (1999). "Characterization of photodamage to escherichia coli in optical traps." *Biophys J* **77**(5): 2856-63.
- Nice, E., B. Catimel, et al. (1997). "Strategies for the identification and purification of ligands for orphan biomolecules." *International Journal of Peptide Research and Therapeutics* **4**(2): 107-120.
- Nikaido, H. (2003). "Molecular basis of bacterial outer membrane permeability revisited." *Microbiol Mol Biol Rev* **67**(4): 593-656.
- Nouwen, N., G. Berrelkamp, et al. (2007). "Bacterial sec-translocase unfolds and translocates a class of folded protein domains." *J Mol Biol* **372**(2): 422-33.
- Oddershede, L., J. K. Dreyer, et al. (2002). "The motion of a single molecule, the lambda-receptor, in the bacterial outer membrane." *Biophys J* **83**(6): 3152-61.
- Odijk, T. (1995). "Stiff chains and filaments under tension." *Macromolecules* **28**(20): 7016-7018.
- Oesterhelt, F., D. Oesterhelt, et al. (2000). "Unfolding pathways of individual bacteriorhodopsins." *Science* **288**(5463): 143-6.
- Ohara, M., H. C. Wu, et al. (1999). "Identification and characterization of a new

Bibliography

- lipoprotein, NlpI, in Escherichia coli K-12." *J Bacteriol* **181**(14): 4318-25.
- Osawa, M., D. E. Anderson, et al. (2008). "Reconstitution of contractile FtsZ rings in liposomes." *Science* **320**(5877): 792-4.
- Park, J. T. (1993). "Turnover and recycling of the murein sacculus in oligopeptide permease-negative strains of Escherichia coli: indirect evidence for an alternative permease system and for a monolayered sacculus." *J Bacteriol* **175**(1): 7-11.
- Park, J. T. (1995). "Why does Escherichia coli recycle its cell wall peptides?" *Mol Microbiol* **17**(3): 421-6.
- Parsons, L. M., F. Lin, et al. (2006). "Peptidoglycan recognition by Pal, an outer membrane lipoprotein." *Biochemistry* **45**(7): 2122-8.
- Pautsch, A. and G. E. Schulz (1998). "Structure of the outer membrane protein A transmembrane domain." *Nat Struct Biol* **5**(11): 1013-7.
- Peters, J. E., T. E. Thaté, et al. (2003). "Definition of the Escherichia coli MC4100 genome by use of a DNA array." *J Bacteriol* **185**(6): 2017-21.
- Piran, U. and W. J. Riordan (1990). "Dissociation rate constant of the biotin-streptavidin complex." *J Immunol Methods* **133**(1): 141-3.
- Priyadarshini, R., M. A. de Pedro, et al. (2007). "Role of peptidoglycan amidases in the development and morphology of the division septum in Escherichia coli." *J Bacteriol* **189**(14): 5334-47.
- Rasmussen, M. B., L. B. Oddershede, et al. (2008). "Optical tweezers cause physiological damage to Escherichia coli and Listeria bacteria." *Appl Environ Microbiol* **74**(8): 2441-6.
- RayChaudhuri, D. and J. T. Park (1992). "Escherichia coli cell-division gene ftsZ encodes a novel GTP-binding protein." *Nature* **359**(6392): 251-4.
- Reithmeier, R. A. and P. D. Bragg (1974). "Purification and characterization of heat-modifiable protein from the outer membrane of Escherichia coli." *FEBS Lett* **41**(2): 195-8.
- Reshes, G., S. Vanounou, et al. (2008). "Cell shape dynamics in Escherichia coli." *Biophys J* **94**(1): 251-64.

Bibliography

- Rhodius, V. A., W. C. Suh, et al. (2006). "Conserved and variable functions of the sigmaE stress response in related genomes." *PLoS Biol* **4**(1): e2.
- Ricard, M. and Y. Hirota (1973). "Process of cellular division in Escherichia coli: physiological study on thermosensitive mutants defective in cell division." I *Bacteriol* **116**(1): 314-22.
- Rice, J. J., A. Schohn, et al. (2006). "Bacterial display using circularly permuted outer membrane protein OmpX yields high affinity peptide ligands." *Protein Sci* **15**(4): 825-36.
- Ried, G., R. Koebnik, et al. (1994). "Membrane topology and assembly of the outer membrane protein OmpA of Escherichia coli K12." *Mol Gen Genet* **243**(2): 127-35.
- Robbins, J. R., D. Monack, et al. (2001). "The making of a gradient: IcsA (VirG) polarity in *Shigella flexneri*." *Mol Microbiol* **41**(4): 861-72.
- Rohrbach, A. (2005). "Stiffness of optical traps: quantitative agreement between experiment and electromagnetic theory." *Phys Rev Lett* **95**(16): 168102.
- Romberg, L., M. Simon, et al. (2001). "Polymerization of Ftsz, a bacterial homolog of tubulin. Is assembly cooperative?" *J Biol Chem* **276**(15): 11743-53.
- Roos, W. (2000). Optical trapping of core-shell particles and dividing Escherichia coli. Amsterdam, University of Amsterdam.
- Roos, W., J. Ulmer, et al. (2005). "Microtubule gliding and cross-linked microtubule networks on micropillar interfaces." *Nano Lett* **5**(12): 2630-4.
- Ruiz, N. (2008). "Bioinformatics identification of MurJ (MviN) as the peptidoglycan lipid II flippase in Escherichia coli." *Proc Natl Acad Sci U S A* **105**(40): 15553-7.
- Ruiz, N., D. Kahne, et al. (2006). "Advances in understanding bacterial outer-membrane biogenesis." *Nat Rev Microbiol* **4**(1): 57-66.
- Sabarth, N., S. Lamer, et al. (2002). "Identification of surface proteins of Helicobacter pylori by selective biotinylation, affinity purification, and two-dimensional gel electrophoresis." *Journal of Biological Chemistry* **277**(31): 27896-27902.
- Sambrook, J. and D. W. Russel (2001). *Molecular cloning: a laboratory manual*. Cold Spring Harbor, New York, Cold Spring Harbor Laboratory Press.

Bibliography

- Sandlin, R. C., K. A. Lampel, et al. (1995). "Avirulence of rough mutants of *Shigella flexneri*: requirement of O antigen for correct unipolar localization of IcsA in the bacterial outer membrane." *Infect Immun* **63**(1): 229-37.
- Scheffers, D. J., L. J. Jones, et al. (2004). "Several distinct localization patterns for penicillin-binding proteins in *Bacillus subtilis*." *Mol Microbiol* **51**(3): 749-64.
- Scheffers, D. J. and M. G. Pinho (2005). "Bacterial cell wall synthesis: new insights from localization studies." *Microbiol Mol Biol Rev* **69**(4): 585-607.
- Schierle, C. F., M. Berkmen, et al. (2003). "The DsbA signal sequence directs efficient, cotranslational export of passenger proteins to the *Escherichia coli* periplasm via the signal recognition particle pathway." *J Bacteriol* **185**(19): 5706-13.
- Schirmer, T., T. A. Keller, et al. (1995). "Structural basis for sugar translocation through maltoporin channels at 3.1 Å resolution." *Science* **267**(5197): 512-4.
- Schroeder, T. E. (1970). "The contractile ring. I. Fine structure of dividing mammalian (HeLa) cells and the effects of cytochalasin B." *Z Zellforsch Mikrosk Anat* **109**(4): 431-49.
- Schroeder, T. E. (1972). "The contractile ring. II. Determining its brief existence, volumetric changes, and vital role in cleaving Arbacia eggs." *J Cell Biol* **53**(2): 419-34.
- Schuhmann, E. and U. Taubeneck (1969). "[Stabil L-forms of several *Escherichia coli* strains]." *Z Allg Mikrobiol* **9**(4): 297-313.
- Schwarz, U. and W. Leutgeb (1971). "Morphogenetic aspects of murein structure and biosynthesis." *J Bacteriol* **106**(2): 588-95.
- Seol, Y., A. E. Carpenter, et al. (2006). "Gold nanoparticles: enhanced optical trapping and sensitivity coupled with significant heating." *Opt Lett* **31**(16): 2429-31.
- Shaner, N. C., R. E. Campbell, et al. (2004). "Improved monomeric red, orange and yellow fluorescent proteins derived from *Discosoma* sp. red fluorescent protein." *Nat Biotechnol* **22**(12): 1567-72.
- Siddiqui, R. A., C. Hoischen, et al. (2006). "The analysis of cell division and cell wall synthesis genes reveals mutationally inactivated ftsQ and mraY in a protoplast-type L-form of *Escherichia coli*." *FEMS Microbiol Lett* **258**(2): 305-11.

Bibliography

- Smith, A. E., Z. Zhang, et al. (2000). "The mechanical properties of *Saccharomyces cerevisiae*." *Proc Natl Acad Sci U S A* **97**(18): 9871-4.
- Smith, S. B., Y. Cui, et al. (1996). "Overstretching B-DNA: the elastic response of individual double-stranded and single-stranded DNA molecules." *Science* **271**(5250): 795-9.
- Smith, S. B., Y. Cui, et al. (2003). "Optical-trap force transducer that operates by direct measurement of light momentum." *Methods Enzymol* **361**: 134-62.
- Smith, S. B., L. Finzi, et al. (1992). "Direct mechanical measurements of the elasticity of single DNA molecules by using magnetic beads." *Science* **258**(5085): 1122-6.
- Smith, S. G., V. Mahon, et al. (2007). "A molecular Swiss army knife: OmpA structure, function and expression." *FEMS Microbiol Lett* **273**(1): 1-11.
- Srinivasan, R., M. Mishra, et al. (2008). "The bacterial cell division protein FtsZ assembles into cytoplasmic rings in fission yeast." *Genes Dev* **22**(13): 1741-6.
- Stricker, J., P. Maddox, et al. (2002). "Rapid assembly dynamics of the *Escherichia coli* FtsZ-ring demonstrated by fluorescence recovery after photobleaching." *Proc Natl Acad Sci U S A* **99**(5): 3171-5.
- Svoboda, K. and S. M. Block (1994). "Biological applications of optical forces." *Annu Rev Biophys Biomol Struct* **23**: 247-85.
- Takeuchi, S., W. R. DiLuzio, et al. (2005). "Controlling the shape of filamentous cells of *Escherichia coli*." *Nano Lett* **5**(9): 1819-23.
- Tan, J. L., J. Tien, et al. (2003). "Cells lying on a bed of microneedles: an approach to isolate mechanical force." *Proc Natl Acad Sci U S A* **100**(4): 1484-9.
- Taschner, P. E., P. G. Huls, et al. (1988). "Division behavior and shape changes in isogenic ftsZ, ftsQ, ftsA, pbpB, and ftsE cell division mutants of *Escherichia coli* during temperature shift experiments." *J Bacteriol* **170**(4): 1533-40.
- Thanedar, S. and W. Margolin (2004). "FtsZ exhibits rapid movement and oscillation waves in helix-like patterns in *Escherichia coli*." *Curr Biol* **14**(13): 1167-73.
- Thie, H., T. Schirrmann, et al. (2008). "SRP and Sec pathway leader peptides for antibody phage display and antibody fragment production in *E. coli*." *N Biotechnol* **25**(1): 49-54.

Bibliography

- Thwaites, J. J. and N. H. Mendelson (1985). "Biomechanics of bacterial walls: studies of bacterial thread made from *Bacillus subtilis*." *Proc Natl Acad Sci U S A* **82**(7): 2163-7.
- Thwaites, J. J. and N. H. Mendelson (1989). "Mechanical properties of peptidoglycan as determined from bacterial thread." *Int J Biol Macromol* **11**(4): 201-6.
- Tikhonova, E. B. and H. I. Zgurskaya (2004). "AcrA, AcrB, and TolC of *Escherichia coli* Form a Stable Intermembrane Multidrug Efflux Complex." *J Biol Chem* **279**(31): 32116-24.
- Tommassen, J. and B. Lugtenberg (1984). "Amino terminus of outer membrane PhoE protein: localization by use of a bla-phoE hybrid gene." *J Bacteriol* **157**(1): 327-9.
- Touze, T., J. Eswaran, et al. (2004). "Interactions underlying assembly of the *Escherichia coli* AcrAB-TolC multidrug efflux system." *Mol Microbiol* **53**(2): 697-706.
- Uehara, T. and J. T. Park (2008). "Growth of *Escherichia coli*: significance of peptidoglycan degradation during elongation and septation." *J Bacteriol* **190**(11): 3914-22.
- van den Ent, F., T. M. Vinkenvleugel, et al. (2008). "Structural and mutational analysis of the cell division protein FtsQ." *Mol Microbiol* **68**(1): 110-23.
- van der Horst, A. (2006). High-refractive index particles in counter-propagating optical tweezers -manipulation and forces -, Utrecht University.
- van der Horst, A., P. D. J. van Oostrum, et al. (2008). "High trapping forces for high-refractive index particles trapped in dynamic arrays of counterpropagating optical tweezers." *Applied Optics* **47**(17): 3196-3202.
- Vandeputte-Rutten, L., M. P. Bos, et al. (2003). "Crystal structure of Neisseria surface protein A (NspA), a conserved outer membrane protein with vaccine potential." *J Biol Chem* **278**(27): 24825-30.
- Vazquez-Laslop, N., H. Lee, et al. (2001). "Molecular sieve mechanism of selective release of cytoplasmic proteins by osmotically shocked *Escherichia coli*." *J Bacteriol* **183**(8): 2399-404.
- Verhoeven, G. S., S. A. Alexeeva, et al. (2008). "Differential surface display of peptides by the transmembrane domain of OmpA." *submitted*.

Bibliography

- Vicente, M., A. I. Rico, et al. (2006). "Septum enlightenment: assembly of bacterial division proteins." *J Bacteriol* **188**(1): 19-27.
- Vinkenvleugel, T. M. (2006). Timing of FtsQ midcell localisation and its interaction with other cell division proteins, University of Amsterdam.
- Visscher, K., S. P. Gross, et al. (1996). "Construction of multiple-beam optical traps with nanometer-resolution position sensing." *IEEE Journal on Selected Topics in Quantum Electronics* **2**(4): 1066-1076.
- Visscher, K., M. J. Schnitzer, et al. (1999). "Single kinesin molecules studied with a molecular force clamp." *Nature* **400**(6740): 184-9.
- Vjestica, A., X. Z. Tang, et al. (2008). "The actomyosin ring recruits early secretory compartments to the division site in fission yeast." *Mol Biol Cell* **19**(3): 1125-38.
- Vollmer, W., D. Blanot, et al. (2008). "Peptidoglycan structure and architecture." *FEMS Microbiol Rev* **32**(2): 149-67.
- Wachi, M. and M. Matsuhashi (1989). "Negative control of cell division by mreB, a gene that functions in determining the rod shape of Escherichia coli cells." *J Bacteriol* **171**(6): 3123-7.
- Wang, M. D., H. Yin, et al. (1997). "Stretching DNA with optical tweezers." *Biophys J* **72**(3): 1335-46.
- Wang, X. and J. Lutkenhaus (1996). "Characterization of the ftsZ gene from Mycoplasma pulmonis, an organism lacking a cell wall." *J Bacteriol* **178**(8): 2314-9.
- Weiss, D. S. (2004). "Bacterial cell division and the septal ring." *Mol Microbiol* **54**(3): 588-97.
- Weiss, D. S., J. C. Chen, et al. (1999). "Localization of FtsI (PBP3) to the septal ring requires its membrane anchor, the Z ring, FtsA, FtsQ, and FtsL." *J Bacteriol* **181**(2): 508-20.
- Wientjes, F. B. and N. Nanninga (1989). "Rate and topography of peptidoglycan synthesis during cell division in Escherichia coli: concept of a leading edge." *J Bacteriol* **171**(6): 3412-9.
- Wientjes, F. B., C. L. Woldringh, et al. (1991). "Amount of peptidoglycan in cell walls of gram-negative bacteria." *J Bacteriol* **173**(23): 7684-91.

Bibliography

- Williams, M. C., J. R. Wenner, et al. (2001). "Effect of pH on the overstretching transition of double-stranded DNA: evidence of force-induced DNA melting." Biophys J **80**(2): 874-81.
- Williams, M. C., J. R. Wenner, et al. (2001). "Entropy and heat capacity of DNA melting from temperature dependence of single molecule stretching." Biophys J **80**(4): 1932-9.
- Xian, M., M. M. Fuerst, et al. (2007). "Sorting signal of Escherichia coli OmpA is modified by oligo-(R)-3-hydroxybutyrate." Biochim Biophys Acta **1768**(11): 2660-6.
- Yao, X., M. Jericho, et al. (1999). "Thickness and elasticity of gram-negative murein sacculi measured by atomic force microscopy." J Bacteriol **181**(22): 6865-75.
- Yuan, C., A. Chen, et al. (2000). "Energy landscape of streptavidin-biotin complexes measured by atomic force microscopy." Biochemistry **39**(33): 10219-23.
- Zagursky, R. J. and M. L. Berman (1984). "Cloning vectors that yield high levels of single-stranded DNA for rapid DNA sequencing." Gene **27**(2): 183-91.
- Zgurskaya, H. I. and H. Nikaido (1999). "AcrA is a highly asymmetric protein capable of spanning the periplasm." J Mol Biol **285**(1): 409-20.
- Zinder, N. D. and W. F. Arndt (1956). "Production of Protoplasts of Escherichia Coli by Lysozyme Treatment." Proc Natl Acad Sci U S A **42**(9): 586-90.

