

Efficient methods for parameter estimation from velocity data CENIIT 99.11

Final report

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Summary of project results

The results from the project can be divided into the following major 5 subprojects (and 2 bonus subprojects):

1. Method development for 3D time resolved phase contrast magnetic resonance imaging (PhD2, PhD3, P2, P3, P9, P12). Here we have focused on the necessary method development of the time resolved three dimensional phase contrast magnetic imaging technique pioneered in Linköping by Wigström (PhD3). Several important improvements were also made in Thunberg (PhD2), where we focused on artefact reduction and image improvement.
2. Non-invasive mapping of the blood flow in the heart and the aorta (PhD1, P1, P6, P10). Here we did our pioneering work on mapping the 4D behaviour of the blood flow through the heart. Special emphasis was put on the left atrium (Fyrenius Licentiate Thesis) and for visualization purposes new tools for automatic feature detection was developed by Heiberg (PhD1). These new tools, based on four dimensional quadrature filters, were subsequently used in the segmentation of the left ventricle for further strain/strain-rate imaging (see 4 below) and wall shear stress imaging (see 5 below).
3. Pressure mapping in the heart (P5, P7). Using the measured velocity data and the Navier-Stokes equations we were able to compute the pressure inside the human heart completely non-invasive by solving a Poisson equation in the measured pressure gradients and thus estimate the pressure field. This was a focus in Ebbers thesis (PhD4).
4. Strain and strain-rate imaging (P4, P8, CP3, CP13, CP15). From the velocity data measured we were able to compute the strain rate (being the symmetric part of the tensor formed by taking the Jacobian of the velocity vector). This new technique was pioneered by Selskog (Lic1). Using the segmentation tools by Heiberg the left ventricular wall was segmented and strain and strain-rate visualized. Continuing work with strain imaging requires the possibility to track individual points (Lagrange view instead of the Euler view used for strain-rate imaging). This has been explored in a collaboration with Stanford University (CP13, CP15)
5. Wall shear stress estimating using MRI and CFD (CP7-12, CP16-19). Using all possible information (geometry and velocity) it is possible to construct individual models of the human aorta for estimation of wall shear stress. This requires all the tools from the above: very accurate MRI techniques for both arterial wall delineation and automatic segmentation, accurate velocity measurements and robust computational fluid dynamics. At the end of the project we are at a point where this is possible (after the end of the project there have been further improvement of the methodology). Patient specific models for diagnosis, intervention planning and follow-up are now a reality!

During the course the work two more areas of research were initiated:

6. Optimization in medicine (P11, P13, CP1, CP2). In order to understand the complex structure of arterial trees, an new optimization technique was developed. These methods

have been used for constructing arterial trees as well as to determine parameters in constitutive equations (Stålhand's Licentiate Thesis)

7. Neuro-mechanical networks for bio-inspired robotics (CP4-CP6). Together with Profs Klarbring and Krus we have initiated a new and exciting field of research into bio-inspired robotics. The project falls in the category "high-risk, high potential impact" and is currently funded by SSF/ProViking.

The project has produced 4 PhDs, one LicEng (and three additional Licentiate's Theses in projects closely associated with CENIIT 99.11) as well as 14 journal publications, 19 conference papers and 35 conference abstracts.

Degrees resulting from the project

The project has resulted in four PhD theses and one licentiate thesis

PhD1. **Einar Heiberg**, PhD 2005: *Automated feature detection in Multidimensional Images*.

PhD2. **Per Thunberg** PhD 2004: *Accuracy and Reproducibility in Phase Contrast Magnetic Resonance Imaging*.

PhD3. **Lars Wigström** PhD, 2003: *Multidimensional Magnetic Resonance Imaging – New Methods for Analysis of Cardiovascular Dynamics*.

PhD4. **Tino Ebbens** PhD, 2001: *Cardiovascular Fluid Dynamics: Methods for Flow and Pressure Field Analysis from Magnetic Resonance Velocity Measurements*.

Lic1. **Pernilla Selskog**, 2004: *Kinematics of the Heart – Strain and Strain-Rate from Time-resolved Three-Dimensional Magnetic Resonance Imaging*.

Additionally there have been three licentiate theses where MK has been assistant supervisor.

- **Johan Lundvall**, 2004: *Reconstruction of velocity data using adjoint optimization* (Licentiate thesis)
- **Jonas Stålhand**, 2003: *Modelling the passive mechanical properties of arteries*. (Licentiate thesis) PhD planned for June 2005
- **Anna Fyrenius**, MD, 1999: *Three-dimensional Intracardiac Flow Studied with Time Resolved Phase Contrast MRI – Blood Flow in the Human Left Atrium and Ventricle*. (Licentiate thesis)

Matts Karlsson was promoted to full professor in 2002 and appointed professor and division chairman in 2003.

MSc projects

- Anders Rönnbrant: Implementing a visualization tool for myocardial strain tensors, LITH-IMT/BMS20-EX--05/403--SE
- Jonas Pettersson: Relative Pressure Estimation in Turbulent Flow using Phase Contrast Magnetic Resonance Imaging, LITH-IMT/BMS20-EX--05/383--SE
- Petter Dyverfeldt: Estimation of Turbulence using Magnetic Resonance Imaging, LITH-IMT/BMS20-EX--04/378--SE
- Henrik Haraldsson: Quantification and Visualization of Shift in Cardiac Situs, LiU-IMT-EX-357
- Katarina Kindberg: Regional Kinematics of the Heart, LITH-IMT/BMS20-EX--03/354--SE
- Nicklas Törnbom: Surface Curvature Estimation and CFD Simulations in Human Abdominal Aortae, LITH-IKP-EX--05/2258—SE
- Fredrik Norling and Fredrik Sundberg: Computational modelling and optimization of arterial tree networks, LITH-IMT/BMS20-EX--05/390—SE
- Andreas Sigfridsson: Hybrid visualization of tensor fields in medical image data, LiU-IMT-EX-313, 2002
- Magnus Lundberg: Two Dimensional Myocardial Strain Rate Estimated from Phase Contrast Magnetic Resonance Imaging Data, LiU-IMT-EX-350, 2003
- Svante Hellzén: Pressure Computation from Magnetic Resonance Velocity Data, LiU-IMT-EX-291, 2000
- Pernilla Björklund: Time-resolved three-dimensional reconstruction of the mitral annulus from echocardiography, LiU-IMT-EX-280, 1999

Staff

The project has funded the research of Matts Karlsson, professor, chairman at Division of Biomedical Modelling and Simulation, Department of Biomedical Engineering as well as partly funded Tino Ebbers, PhD, assistant professor, Department of Medicine and Care, Lars Wigström, PhD, currently doing a post-doc at Lucas Center for Magnetic Resonance Imaging and Spectroscopy Research at Stanford University and Einar Brandt, PhD, currently performing post-doc research at Lund University Hospital. The research group also consists of Per Thunberg, PhD, research leader at Department of Biomedical Engineering, Örebro University Hospital and Jonas Stålhand, PhD, research assistant at Division of Mechanics. Several PhD-students have been partly funded by the project: Johan Lundvall, PhD-student at Department of Mathematics, Johan Svensson, PhD-student at Department of Mechanical Engineering and Roland Gårdhagen, PhD-student at Department of Mechanical Engineering. The group also consists of Katarina Kindberg, PhD-student at Division of Biomedical Modelling and Simulation, Department of Biomedical Engineering and Henrik Haraldsson, PhD-student at Division of Biomedical Modelling and Simulation, Department of Biomedical Engineering as well as Mattias Sillén, Industry PhD student and Pernilla Selskog, MSEE, LicEng, currently with SAAB Avionics in Jönköping

Industrial contacts and cooperation

The industrial contacts within the CENIIT-project has been focused to two quite different areas:

- Collaboration with vendors of medical imaging systems, in particular Philips and GE Medical systems for MRI scanners and Siemens for CT scanners. These contacts have been made through the recently established Center for Medical Image Science and Visualization (CMIV), a joint research collaboration between the Institute of Technology, the University Hospital and industry. The work within the CENIIT project has been important for its establishment.
- Collaboration with software companies (codes for computational fluid dynamics, e.g. Fluent and CFD++), FOI/FFA with their code EDGE as well as SAAB Aircraft in Linköping (users of and developers for EDGE).

The project has collaborated extensively with former CENIIT project holders and completely new research areas have been established: Anders Klarbring (topology optimization in medicine) and Anders Klarbring and Petter Krus (Neuromechanical networks for bio-inspired robotics). We were also collaborating extensively with Joakim Pettersson.

Establishment of a new division

The funding from the the CENIIT project has been instrumental for the formation of the new division Biomedical Modelling and Simulation at Department of Biomedical Engineering. Matts Karlsson is the founding chairman of the division. The research at the division of biomedical modelling and simulation includes the vast area from traditional basic physiology to advanced clinical applications. Presently, one focus is the biofluid mechanics of the heart and the greater vessels, another the mechanics of the myocardium. In biomedical modelling and simulation we are using tools from mathematics, mechanics and physics in order to analyse structure and function of complex biological systems. The advanced model development is based on high quality measurements. Currently, non-invasive measurement techniques are utilized combined with computer models for data assimilation. The rapid development in computers enables the development of individually based models for advanced

diagnosis, intervention planning and follow-up. The research area is cross-disciplinary and presently we are participating in the development of Center for Medical Image Science and Visualization (CMIV), a joint effort between the University and the University Hospital. The division has a long standing research collaboration with the Department of Mechanical Engineering (IKP) and National Supercomputer Centre (NSC) at Linköpings universitet.

Publications (journal papers)

- P1. A Fyrenius, L Wigström, AF Bolger, T Ebbers, P Öhman, M Karlsson, B Wranne and J Engvall: Pitfalls in Doppler Evaluation of Diastolic Function: Insights from Three-Dimensional Magnetic Resonance Imaging. *J Am Soc Echocardiogr*, Oct;12(10):817-826, 1999
- P2. L Wigström, T Ebbers, A Fyrenius, M Karlsson, J Engvall, B Wranne and AF Bolger: Particle Trace Visualization of Intracardiac Flow Using Time-Resolved 3D Phase Contrast MRI, *Magnetic Resonance in Medicine*, Vol 41:793-799, 1999
- P3. P Thunberg, L Wigström, J Engvall, B Wranne and M Karlsson: Correction for Acceleration-Induced Displacement Artifacts in Phase Contrast Imaging. *Magnetic Resonance in Medicine*, Vol 43:734-738, 2000.
- P4. J-U Voigt, MF Arnold, M Karlsson, L Hübbert, T Kukulski, L Hatle and GR Sutherland: Assessment of Regional Longitudinal Myocardial Strain Rate Derived from Doppler Myocardial Imaging Indexes in Normal and Infarcted Myocardium. *J Am Soc Echocardiogr*, Vol 13:588-598, 2000.
- P5. T Ebbers, L Wigström, AF Bolger, J Engvall and M Karlsson: Estimation of Relative Cardiovascular Pressures Using Time-resolved Three-Dimensional Phase Contrast MRI. *Magn Res Imaging*, 2001;45(5):872-9.
- P6. A Fyrenius, L Wigström, T Ebbers, M Karlsson, J Engvall and AF Bolger: Three-Dimensional Flow in the Human Left Atrium. *HEART* 2001;86(4):448-55.
- P7. T Ebbers, L Wigström, AF Bolger, B Wranne and M Karlsson: Non-invasive Measurement of Time-varying Three-Dimensional Flow and Relative Pressure Fields within the Human Heart. *J Biomech Eng*. Jun;124(3):288-93, 2002
- P8. P Selskog, E Brandt Heiberg, T Ebbers, L Wigström and M Karlsson: Kinematics of the Heart: Strain Rate Imaging from Time-Resolved Three-Dimensional Phase Contrast MRI, *IEEE Trans Med Imaging*. Sep;21(9):1105-9, 2002
- P9. P Thunberg, L Wigström, T Ebbers and M Karlsson: Correction for displacement artifacts in 3D phase contrast imaging. *J Magn Reson Imaging*. Nov;16(5):591-7, 2002
- P10. E Brandt Heiberg, T Ebbers, L Wigström and M Karlsson: Three Dimensional Flow Characterization using Vector Pattern Matching, *IEEE Trans Visualization and Computer Graphics*, Vol 9 No pp313-319, 2003
- P11. A Klarbring, J Petersson, B Torstenfelt and M Karlsson: Topology Optimization of Flow Networks, *Comput Methods Appl Mech Engrg* Vol 192, pp 3909-3932, 2003
- P12. P Thunberg, M Karlsson, L Wigström: Accuracy and Reproducibility in Phase Contrast Imaging using SENSE, *Magn Reson Med*. Nov;50(5):1061-8, 2003
- P13. J Stålhånd, A Klarbring and M Karlsson: Towards in vivo aorta material identification and stress estimation. *Biomech Model Mechanobiol*. Mar;2(3):169-86, 2004
- P14. C Carlhäll, L Wigström, E Heiberg, M Karlsson, AF Bolger and E Nylander: Contribution of Mitral Annular Excursion and Shape Dynamics to Total Left Ventricular Volume Change, *Am J Physiol Heart Circ Physiol*. Oct;287(4):H1836-41, 2004

Publications (conference papers)

- CP1. T Borrvall, M Karlsson, A Klarbring, J Petersson and B Torstenfelt: Optimization in Solid, Fluid and Bio-Mechanics, L Beldiem, O Dahlbom, A Olsson, NS Ottosen and G Sandberg (eds.). Proceedings of 14th Nordic Seminar on Computational Mechanics, 2001. 4p
- CP2. T Borrvall, A Klarbring, J Petersson, B Torstenfelt and M Karlsson: Topology Optimization in Fluid Mechanics. Proceedings of 5th World Congress on Computational Mechanics WCCM, July 12-17, 2002, Vienna, Austria. (Editors: HA Mang, FG Rammerstorfer, K Eberhardsteiner; Publisher Vienna University of Technology, Austria, ISBN 3-9501554-0-6, <http://wccm.tuwien.ac.at>)
- CP3. P Selskog, B Torstenfelt, T Ebbens, L Wigström and M Karlsson: Kinematics of the Heart – Finite Elements and 3D Time-Resolved Phase-Contrast Magnetic Resonance Imaging. Proceedings of 9th FEM Workshop at University of Ulm, Germany, July 18-19, 2002. 10p
- CP4. P Krus and M Karlsson: Self-organising Multifunctional Neuro-Mechanical Networks. Proceedings of Power Transmission and Motion Control 02, Bath, UK, 2002. 10p
- CP5. M Sethson, M Karlsson and P Krus: Neuro-Mechanical Networks as an Architecture for System Design, Proceedings of AAAI Spring Symposium on Computational Synthesis, Stanford University, USA, March 24-26, 2003. 10p
- CP6. M Sethson, P Krus and M Karlsson: Simulation of Self-Organizing Structures using Neuro-Mechanical Networks, Presentation at ESM2003, Nottingham, UK, June, 2003, 10p
- CP7. J Lundvall, P Weinerfelt and M Karlsson: Reconstruction of velocity data using optimization, Presentation at Second MIT Conference on Computational Fluid and Solid Mechanics, MIT, Boston, USA, June 2003. 4p
- CP8. M Karlsson: Biomedical Modelling and Simulation – Towards Individual Models of the Human Cardiovascular System. In: Proceedings of 16th Nordic Seminar on Computational Mechanics, KM Mathisen, T Kvamsdal, KM Okstad (Eds.), 16-18 October, Trondheim Norway, 2003, 4p
- CP9. J Svensson, R Gårdhagen and M Karlsson: Geometry Considerations in Patient Specific Models of a Human Aorta with Stenosis and Aneurysm, Proceedings of Third International Conference on Computational Fluid Dynamics (ICCFD3), July 12-16, Toronto, Canada, 2004, 6p
- CP10. R Gårdhagen, J Svensson and M Karlsson: Complex Flow Patterns in Realistic Geometry of Human Aorta, Proceedings of Third International Conference on Computational Fluid Dynamics (ICCFD3), July 12-16, Toronto, Canada, 2004, 2p
- CP11. J Svensson, R Gårdhagen and M Karlsson: Patient specific human aorta geometry – influence on CFD simulation parameters, Proceedings of 17th Nordic Seminar on Computational Mechanics, October 15-16, Stockholm, Sweden, 2004, 4p
- CP12. R Gårdhagen, J Svensson and M Karlsson: CFD studies of rotating blood flows in human aorta – a parameter estimation, Proceedings of 17th Nordic Seminar on Computational Mechanics, October 15-16, Stockholm, Sweden, 2004, 4p
- CP13. K Kindberg and M Karlsson: Cardiac wall strain variations due to compressibility, Proceedings of 17th Nordic Seminar on Computational Mechanics, October 15-16, Stockholm, Sweden, 2004, 4p
- CP14. K. Kindberg and M. Karlsson: Mitral valve opening in the failing heart. In proceedings of *13th Nordic Baltic Conference, Biomedical Engineering and Medical Physics*, Umeå, Sweden, 2005, 2p
- CP15. K. Kindberg and M. Karlsson: Transmural myocardial strain distribution - theoretical results and in vivo data. In proceedings of *13th Nordic Baltic Conference, Biomedical Engineering and Medical Physics*, Umeå, Sweden, 2005, 2p

- CP16. R Gårdhagen, J Svensson, D Loyd and M Karlsson: Non-Newtonian Effects on Wall Shear Stress in a Human Aorta with Coarctation and Dilatation, In proceedings of *13th Nordic Baltic Conference, Biomedical Engineering and Medical Physics*, Umeå, Sweden, 2005, 2p
- CP17. J Svensson, R Gårdhagen, D Loyd and M Karlsson Wall Back Flow in Human Aorta: Influence of Geometry, In proceedings of *13th Nordic Baltic Conference, Biomedical Engineering and Medical Physics*, Umeå, Sweden, 2005, 2p
- CP18. R. Gårdhagen, J. Svensson and M. Karlsson: Wall Shear Stress in a Human Aorta with Constriction and Aneurysm -- non-Newtonian Effects for Unsteady Flows. *2005 Summer Bioengineering Conference*. Vail, USA, June 2005, 2p
- CP19. J.Svensson, R. Gårdhagen and M. Karlsson: Comparison of Flow Parameters Between Different Geometries of a Human Aorta with Carctation and Aneurysm. *2005 Summer Bioengineering Conference*. Vail, USA, June 2005, 2p

Publications (conference abstracts)

- CA1. L Wigström, T Ebbers, A Fyrenius, M Karlsson, J Engvall, B Wranne and AF Bolger: The Effects from Maxwell Terms on Particle Traces Calculated from 3D Cine Phase Contrast Images. Proc of SCMR-98, January 30 - February 1, Atlanta, USA, (*Journal of Cardiovascular Magnetic Resonance*, Vol 1, No 1, p 93, 1999).
- CA2. AF Bolger, L Wigström, J Engvall, P Öhman, M Karlsson and B Wranne: Diastolic Function in LVH: Comparison of Doppler with Phase Contrast 3D MRI, Presented at American College of Cardiology (ACC), March 29 - April 1, Atlanta, USA, 1998.
- CA3. L Wigström, M Karlsson, J Engvall, B Wranne and AF Bolger: A Novel Method for Determining Intracardiac Gradients Using Time-resolved 3D MRI Data, Presented at American College of Cardiology (ACC), March 29 - April 1, Atlanta, USA, 1998.
- CA4. A Fyrenius, L Wigström, T Ebbers, M Karlsson, J Engvall, B Wranne och AF Bolger: Intrakardiella flöden studerade med 3D MR faskontrast, Presenterad vid Svensk Förening för Klinisk Fysiologi Årsmöte, 7-8 Maj, Uppsala, 1998.
- CA5. A Fyrenius, T Ebbers, L Wigström, M Karlsson, J Engvall, B Wranne and AF Bolger: Complex Directions of Pulmonary Venous Inflow: Intuitive Display with 3D MRI Phase Contrast, Presented at American Society of Echocardiography Annual Meeting (ASE98), June 10-13, San Francisco, USA, 1998.
- CA6. T Ebbers, A Fyrenius, L Wigström, AF Bolger and M Karlsson: Calculation of Relative Cardiac Pressure Along Streamlines Using Time-Resolved 3D Phase Contrast MRI, Proceedings of 2nd SCMR Meeting, January 22-24, Atlanta, USA, 1999
- CA7. A Fyrenius, T Ebbers, L Wigström, M Karlsson, J Engvall, B Wranne and AF Bolger: Discrete Three-Dimensional Pathways of Right and Left Pulmonary Venous Inflow Studied with Phase Contrast MRI, Presentation at ACC99, March 7-10, New Orleans, USA, 1999 (*JACC*, Vol 33, No 2, p477A)
- CA8. J-U Voigt, M Arnold, T Kukulski, M Karlsson and GR Sutherland: Is Strain Rate Imaging Applicable to the Clinical Setting? - Preliminary In Vivo Data. Presented at ACC99, March 7-10, New Orleans, USA, 1999 (*JACC*, Vol 33, No 2, p429A)
- CA9. A Fyrenius, T Ebbers, L Wigström, M Karlsson, B Wranne, AF Bolger and J Engvall: Left Atrial Vortices Studied with 3D Phase Contrast MRI. Presentation at Kliniskt Fysiologiskt Årsmöte, Linköping, 14-16 april, 1999
- CA10. P Thunberg, L Wigström, B Wranne and M Karlsson: A Post Processing Method for Correction of Acceleration-Induced Displacement Artifacts. Presented at International Society for Magnetic Resonance in Medicine SMR99, 22-28 May, Philadelphia, USA, 1999

- CA11. T Ebbers, L Wigström, A Fyrenius, AF Bolger and M Karlsson: Particle Trace Visualization of Cardiac Flow Patterns using 3D Phase Contrast MRI: An in vitro Comparison with Streamlines Created using Dye. Presented at International Society for Magnetic Resonance in Medicine SMR99, 22-28 May, Philadelphia, USA, 1999
- CA12. L Wigström, A Fyrenius, T Ebbers, M Karlsson, J Engvall, B Wranne and AF Bolger: Visualization and Quantification of Intra-Cardiac Flow Patterns Based on Time-Resolved 3D Phase Contrast Data, Presented at ISMRM-Workshop, London, UK, 28-30 June, 1999
- CA13. M Karlsson, D Loyd, P Ask, K Lindström and H Elmqvist: CORTECH/tutor - a Distributed Biomedical Engineering Graduate Training Initiative. Presented at IEEE/EMBS 1999, Atlanta, USA, 13-17 October, 1999
- CA14. A Fyrenius, T Ebbers, L Wigström, M Karlsson, B Wranne, J Engvall, AF Bolger: Quantification of intra ventricular vortices from 3D phase contrast MRI, Presented at American Heart Association 72nd Scientific Session, Atlanta, USA, 7-11 November, 1999.
- CA15. P Björklund, E Brandt, L Wigström, A Fyrenius, B Wranne and M Karlsson: Time Resolved Three-Dimensional Reconstruction of the Mitral Annulus, Presented at European Society of Cardiology, Vienna, December 9-12, 1999.
- CA16. P Selskog, E Brandt, L Wigström and M Karlsson: Quantification of Myocardial Strain-rate from 3D Cine Phase Contrast. Presentation at ESMRMB-2000, Paris, France.
- CA17. P Thunberg, L Wigström, B Wranne, J Engvall and M Karlsson: Accelerationens inverkan på mätnoggrannheten vid hastighetsmätningar med MR. Presentation at Svenska Läkaresällskapets Riksstämma 2000.
- CA18. E Brandt, T Ebbers, L Wigström, J Engvall and M Karlsson: Automatic Detection of Vortical Flow Patterns from Three-dimensional Phase Contrast MRI. Proceedings of International Society for Magnetic Resonance in Medicine, 8th Scientific Meeting & Exhibition, Glasgow, Scotland, 2001.
- CA19. T Ebbers, L Wigström, AF Bolger, B Wranne and M Karlsson: Estimation of Time-varying Three-dimensional Relative Pressure Fields within the Human Heart. Proceedings of International Society for Magnetic Resonance in Medicine, 8th Scientific Meeting & Exhibition, Glasgow, Scotland, 2001.
- CA20. P Selskog, E Brandt, L Wigström and M Karlsson: Visualization of myocardial strain-rate tensors from time-resolved 3D cine phase contrast MRI, Proceedings of International Society for Magnetic Resonance in Medicine, 8th Scientific Meeting & Exhibition, Glasgow, Scotland, 2001.
- CA21. M Karlsson: Hjärtats mekanik, Invited presentation, Proceedings of Svenska mekanikdagarna SMD01, p 16-17, Linköping, Sweden, June 11-13, 2001.
- CA22. P Selskog, E Brandt, L Wigström and M Karlsson: Töjningshastighet i hjärtmuskeln från 3D cine faskontrast MR. Proceedings of Svenska mekanikdagarna SMD01, p 34-35, Linköping, Sweden, June 11-13, 2001.
- CA23. E Brandt, T Ebbers, L Wigström and M Karlsson: Automatisk flödes-karaktärisering av tredimensionella vektorfält. Proceedings of Svenska mekanikdagarna SMD01, p 61-62, Linköping, Sweden, June 11-13, 2001.
- CA24. M Karlsson, T Ebbers and L Wigström: A Combined CFD and MRI Approach to Cardiovascular Fluid Dynamics. Proceedings of "The Integrated Heart: Cardiac Structure and Function", Satellite meeting of the 34th World Congress of the International Union of Physiological Sciences. Queenstown, NZ, 19-22 Aug, 2001. Invited presentation.
- CA25. T Borrvall, A Klarbring, J Petersson, B Torstenfelt and M Karlsson: Topology Optimization in Fluid Mechanics. Presented at 2nd Max Planck Workshop on Engineering Design Optimization, October 12-14, 2001, Nyborg, Denmark

- CA26. P Thunberg, T Ebbers, M Karlsson and L Wigström: Comparison of blood flow measurements using SENSE at different reduction factors. Presentation at ISMRM-02, Honolulu, Hawaii, USA, May 2002
- CA27. P Selskog, E Heiberg, T Ebbers, L Wigström and M Karlsson: Kinematics of the Heart, Presentation at 4th World Congress Biomechanics, Calgary, Canada, 4-9 August, 2002
- CA28. P Thunberg, L Wigström, T Ebbers och M Karlsson: Ny metod för korrektion av artefakter i 3D-hastighetsfält uppmätta med MR. Presentation at Svenska Läkaresällskapets rikstämma, Göteborg, 26-28 November 2002
- CA29. A Klarbring, J Petersson, B Torstenfelt and M Karlsson: Topology Optimization of Flow Networks, Presentation at Euromech 442: Colloquium on Computer-Aided Optimization of Mechanical Systems, Nürnberg, Germany, February 23-27, 2003
- CA30. P Thunberg, M Karlsson and L Wigström: Reproducibility in Phase Contrast Imaging using SENSE, Presented at 11th Annual ISMRM, 10-16 May, Toronto, Canada, 2003. (Held in July due to SARS)
- CA31. P Thunberg, M Karlsson and L Wigström: Accuracy and reproducibility in flow measurements using SENSE, Presentation at ESMRMB-03, Rotterdam, 2003
- CA32. J Svensson, R Gårdhagen, T Länne and M Karlsson: Comparison of Wall Shear Stress Between Sifferent Segmentations of a Human Aorta with Coarctation and Aneurysm. Accepted for presentation at Svenskt Kardiovaskulärt Vårnöte, 27-29 april, Malmö, Sweden, 2005
- CA33. E Heiberg, L Wigström, M Carlsson and M Karlsson: Three dimensional Time Resolved Segmentation of the Left Ventricle, Accepted for presentation at International Society for Magnetic Resonance in Medicine 13th Scientific Meeting, South Beach, Florida, 7-13 May, 2005
- CA34. R. Gårdhagen, J.Svensson and M. Karlsson: Non-Newtonian Effects in Blood Flow Through Constriction and Dilatation - Steady Flow. SMD 05 Svenska Mekanikdagar. Lund, Sverige June 2005.
- CA35. J. Svensson, R. Gårdhagen, and M. Karlsson: Wall Back Flow Variations During Pulsative Flow in a Human Aorta. SMD 05, Svenska Mekanikdagar. Lund, Sverige, 2005.