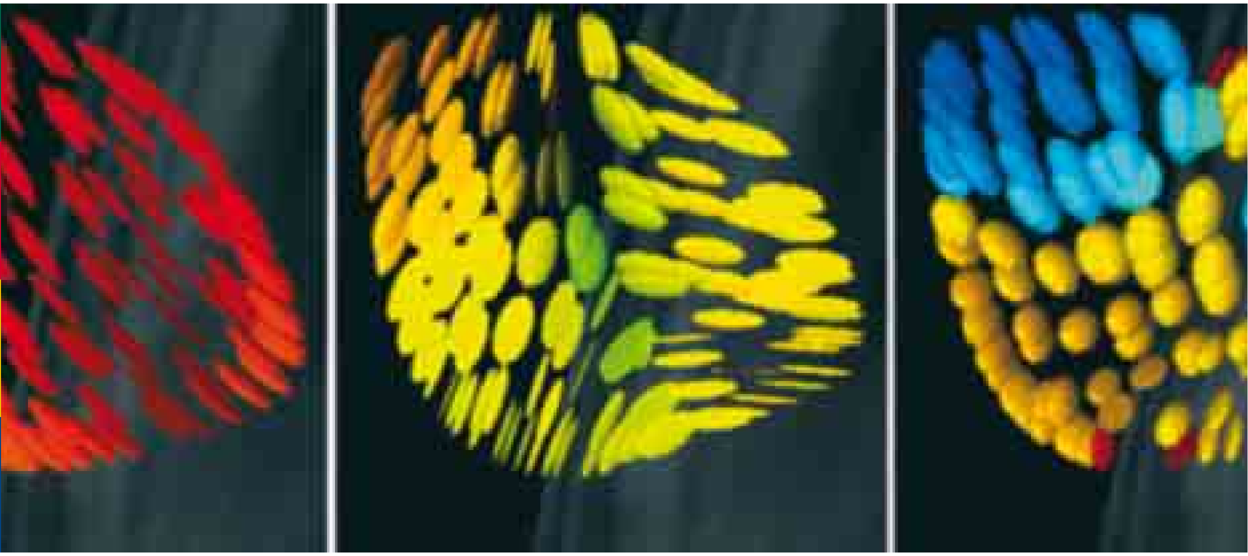
Vetenskapsrådet

INTERNATIONAL EVALUATION OF SWEDISH RESEARCH IN BIOMEDICAL ENGINEERING



VETENSKAPSRÅDETS RAPPORTSERIE 8:2006

International Evaluation of

SWEDISH RESEARCH IN BIOMEDICAL ENGINEERING

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Biomedical Engineering

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Swedish Agency for Innovation Systems, VINNOVA
Swedish Foundation for Strategic Research
Swedish Research Council, Vetenskapsrådet

Jointly organized by the funding bodies
in Stockholm on 14-21 January 2006

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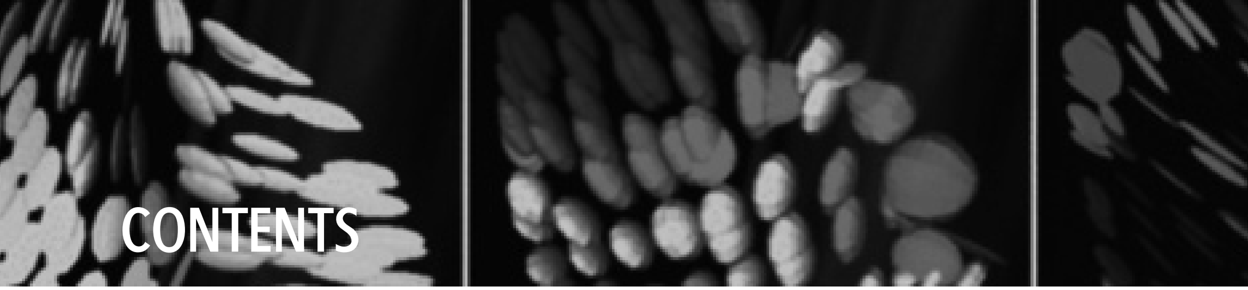

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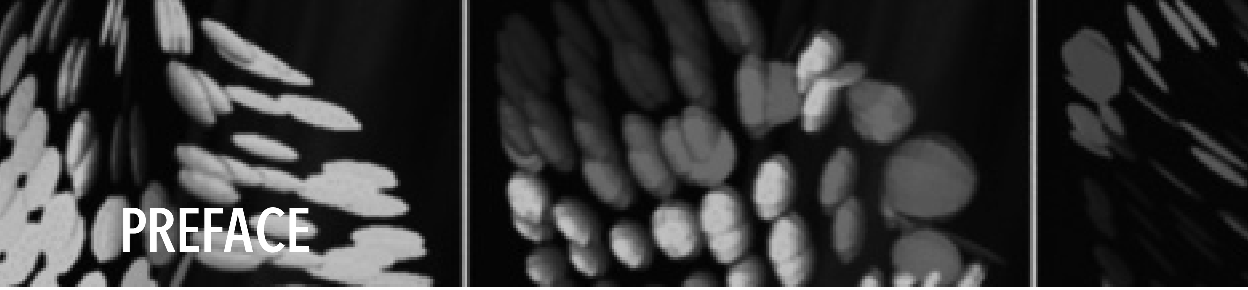


PREFACE

Following informal discussions between the Swedish Research Council (Vetenskapsrådet, VR) and the Swedish Foundation for Strategic Research, it was proposed in the autumn of 2004 to conduct a joint evaluation of Swedish research in Biomedical Engineering (BME); as an academic activity in Swedish commonly, but not always, called *Medicinsk teknik*. As also VINNOVA – the Swedish Agency for Innovation Systems - and its predecessors NUTEK and STU historically have played an important part in funding BME activities in Sweden, all three financing bodies agreed to carry out the evaluation together.

Having different responsibilities, but to some extent similar or overlapping roles and modes of operation in the Swedish research system, these three organisations together provide the large majority of grants from public sources in Sweden that support research in, and related to, Biomedical Engineering. Several research groups have funding from at least two, sometimes all three bodies – apart from other, more scattered national sources and from international sources as the European Union.

In accordance with their respective statutes, as laid down by the Government, all three bodies are charged with evaluating the research activities that they support. This is normally done according to procedures within each single funding body. Of the three, the Swedish Research Council and its predecessors (in particular, the former Natural Science Research Council, NFR, and the Research Council for Engineering Sciences, TFR, but also the Medical Research Council, MFR) have a tradition in conducting evaluations of entire fields of science or research from time to time. VINNOVA (and NUTEK) and the Foundation, on the other hand, due to their respective roles and modes of work, mainly conduct evaluations at programme level, primarily of specific efforts such as VINNOVA's Competence Centres as well as the Foundation's comprehensive programmes and, later, its Strategic Research Centres.

Against this background, the three funding bodies in 2005 decided to jointly appoint a panel of prominent international experts to carry out the evaluation – the first comprehensive one made of this field in Sweden. The panel membership was based upon recommendations from the three bodies, including some informal consultation with present or former members of the BME Review Panel within the Swedish Research Council and with some individual experts in the panel.

Photo: Ingemar Björklund

The panel members, top left: Robert S. Reneman, Robert M. Nerem, Stephen Badylak, Jon Cooper. Bottom left: Azam Niroomand-Rad and Richard Kitney.

The panel members appointed were:

Dr Robert M Nerem, Professor & Director, Parker H Petit Institute for Bioengineering and Bioscience, Georgia Institute of Technology, Atlanta, and until recently Senior Advisor of the National Institute for Biomedical Imaging and Bioengineering, Washington DC (Chairman of the Panel).

Dr Stephen Badylak, MD, PhD, Research Professor in the Department of Surgery; Director within the Institute for Regenerative Medicine, University of Pittsburgh.

Dr Jon Cooper, Professor of Bioelectronics, Department of Electronics and Electrical Engineering, University of Glasgow.

Dr Richard Kitney, Professor of Biomedical Systems Engineering, Imperial College of Science, Technology and Medicine, London.

Dr Azam Niroomand-Rad, Professor of Radiation Medicine and Director of

Clinical Physics, Georgetown University, Washington DC, and President of the International Organization for Medical Physics (IOMP).

Dr Robert S Reneman, MD, PhD, Professor of Cardiovascular Research, Department of Physiology, Cardiovascular Research Institute, Maastricht, NL.

Also present during the evaluation week was Dr Stina Gestrelius, who was appointed by the VR Scientific Council for Natural and Engineering Sciences, as one of its members, to act as "Swedish rapporteur" of the panel visit. Among other tasks, the Rapporteur is to ensure that conflict of interest issues are managed in a proper way. VINNOVA and the Foundation invited two experts from Swedish industry with good knowledge of the research system to serve as informal observers throughout most of the evaluation, Gösta Sjöholm and Dr Håkan Håkanson (both with a background from larger and smaller medical device and biotech companies).

The planning and organisation of the entire review process was carried out by a joint committee with Sofie Björling and Margareta Eliasson from VR, Maj-Lis Ströman from VINNOVA, and Lena-Kajsa Sidén from the Foundation.

On behalf of the three funding bodies we, the undersigned, hereby express our deepest gratitude to the participating researchers, to the Evaluation Panel for conducting the evaluation and also for their support in finalising this report, and to other participants as mentioned above.

Stockholm in May, 2006

Arne Johansson
Swedish Research Council
Natural and Engineering Sciences

Håkan Billig
Swedish Research Council
Medicine

Karin Markides
VINNOVA

Lars Rask
Swedish Foundation
for Strategic Research

PANEL'S GENERAL RECOMMENDATIONS

The future economy of Sweden, as with other highly developed countries, will be knowledge based, and this thus must dictate Sweden's strategy for investing in research. This is true in general, and this also is true for biomedical engineering.

General recommendations are as follows:

1. For biomedical engineering, the investment in research must extend beyond the "classic" areas historically associated with this field.

   In many developed countries the term biomedical engineering has a very different meaning to that of even a decade ago. Many areas of clinical medicine and the life sciences are progressing rapidly. One key example is the molecular biology revolution (as evidenced by the initial sequencing of the human genome). This is resulting in the development of a new medicine – a molecular based medicine. Almost all the new areas in medicine and the life sciences depend heavily on engineering.

2. The investments in biomedical engineering research must leverage the strength Sweden has both in clinical medicine and in the life sciences.

   It has been clearly shown that in developed countries, which lack major natural resources, the wealth of the nation is, to a significant extent, dependent on the ability to create new industries. These are frequently based upon intellectual property generated by the country's research universities (i.e. universities with a strong research base). In the 21st century, with the rapid rise of the Asian economies, this is not only true today, but will become increasingly important in the future.

3. There should be a significant increase in funding for biomedical engineering research with programs ranging from regular research grants to strategic research initiatives.

- Within this there should be increased funding for high risk research, with less investments in projects that involve incremental advances.

During the Review in has become clear that the current academic career structure (see General Issues) has the effect of causing researchers to submit safe, incremental projects which they believe (on the basis of their experience) are more likely to be funded. Under the present system, in many instances, highly capable researchers do not submit grant applications on the basis of what they know to be important and challenging new areas, but rather on the basis of what research will be funded – and hence keep their research group intact.

- Strategic research initiatives should network the strengths locally and within the country, so as to achieve a critical mass of activity that is internationally competitive and provides an integrated educational program.

- Regular research grants should be funded for a sufficient duration to allow for the complete support of a PhD student's dissertation research.

4. As young scientists represent the foundation of the future knowledgebased economy, special attention must be placed on their development; the failure to do so will result in a future lack of senior academic leadership.

- This must include the establishment of a formal career track for young faculty, one that allows an individual's career to progress step-by-step.

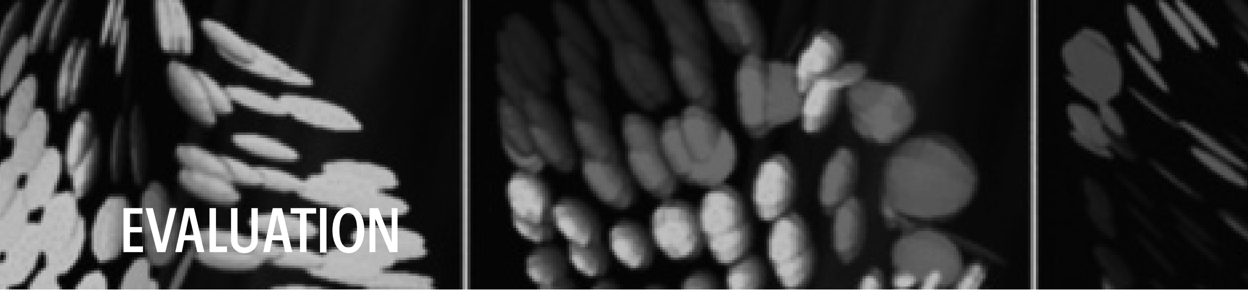
  By a formal Career Track we mean a clearly defined career path that is entered at the postdoctoral level and on which there is a progression from the lowest rank of the academic ladder to Full Professor. Hence, a person is appointed to the permanent academic staff of the university and is supported, in terms of salary, from central university funds. Promotion should be on the basis of the academic record of the individual – in terms of research, teaching and administration. We would like to point out that this is exactly the system which is employed by leading universities in many countries, including European countries which are in all other respects similar to Sweden.

- It also must include special research grant programs that foster the establishment of an independent research program by a beginning faculty member.

Priority areas that have been identified for future research investments are in alphabetical order as follows:

1. Biomaterials
2. Clinical information systems
3. Image-guided interventions
4. Implanted biosensors, integrated diagnostics
5. Molecular imaging
6. Systems biology including integrated modelling
7. Tissue engineering and regenerative medicine

With the significant investment by Sweden in these research areas, the country has the opportunity to move to more of a leadership position in the world. The future thus has the potential to be a bright one; however, to realize this the funding agencies in Sweden must make the decision to foster the type of changes noted in this report and to invest in the priority areas identified.



EVALUATION

Purpose of the evaluation

The overarching purpose of the evaluation was to inform the Swedish Research Council, VINNOVA and the Foundation about the position of Swedish Biomedical Engineering research as seen in an international context. This was based upon the scientific quality and other relevant qualities of the research activities that have been conducted from 1997 up to the present. The overall research activities were thus viewed as the principal elements of the evaluation.

As BME as a field is very heterogeneous, drawing upon several underlying areas of science and engineering, it was decided to assist the Panel by arranging a distance peer review preceding the panel visit. The latter drew upon the more detailed expertise of a separate, wider group of evaluators with specific competence in the various subfields concerned. Thus the task of the Panel was to integrate and synthesise an overall picture of the position of Swedish research in BME, based upon background reports provided by the grant holders, evaluation reports from the distance evaluators, presentations given at hearings arranged with the grant holders, and the Panel's own deliberations and judgement. A two-tier evaluation of a research field of the kind indicated knowingly has not been conducted before in Sweden.

In its overall assessment of the status of Swedish BME research the Panel was encouraged to comment also on any structural or other generic problems identified.

In addition the panel was given the special charge to comment on the design of a joint Call for Proposals that the three funding bodies are planning to announce in the spring of 2006 under the general working theme, "Medicinsk teknik för bättre hälsa" [1]. Making available, as a point of departure, a total amount of SEK 36 million (appr. USD 4,5 million) for three years (i.e. 2007-2009), and noting the need for interdisciplinary collaboration between engineering and medicine, the funding bodies thus asked the Panel to provide recommendations (Recommendations for a joint call for proposals) as to scope, priority directions, ways to organise collaboration, forms for support, size of grants, etc, on the basis of the results of the evaluation and of its own assessment of Swedish strengths and weaknesses in an international perspective.

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1 *Here, the second half means "for better health". The first half could translate to "Biomedical engineering" as well as "Medical technology"; the announcement will give more details.*

Evaluation process

Each research project or research programme supported by VR, VINNOVA, and the Foundation has a principal grant holder who is responsible for the project or the programme. For the purpose of the evaluation, initially 89 grant holders were identified as having been funded by one or more of the three bodies organising the evaluation (incl. the predecessors of VR and VINNOVA) some time between 1997 and 2005, i.e. not necessarily during the entire period. The identification was based on a rather operational definition of "Biomedical Engineering and related", based upon sub-fields used by the VR-NT Council and some of the main tracks of international BME conferences (see list below; both research groups and distance reviewers were asked to identify their specialities according to this classification). To be meaningfully included in the evaluation, the grant holders also had to fulfil certain criteria relating to minimum amount of grants received and to year of first payment; the latter to avoid evaluating new entrants too early.

Biomedical Engineering sub-fields used in parts of the evaluation

1 Biomaterials, tissue engineering
2 Imaging technologies (outside other headings)
3 Biomechanics
4 Biooptics
5 Biosensors, micro-nano-(bio)technologies
6 Cardiovascular
7 Physiological measurement technology and modelling
8 Medical image and signal processing
9 Medical informatics
10 Medical radiation physics
11 Neuro (biology, engineering, informatics)
12 Technical audiology
13 Therapeutic technologies (various)
14 Ultrasound
15 Other

The 89 grant holders were asked to write their background reports into a web-based form intended for internet submission only. Eventually, out of the 89 grant holders invited to participate, 12 were left out at their own request due to reasons as leaving the field, sickness, moving abroad, or in a few cases due to the actual work period being too short. Another 17 of the 89 chose to use the option to report jointly with another grant holder, with the latter as the "official" submitter of the joint report. Although it often was the case, this setup did not necessarily mean that the submitter held a superior or more senior position relative to other grant holders contributing to the background report. Thus, the contributing grant holders to certain reports may be thought of as "equals", working in different areas under a more or less common "umbrella".

In this way, 60 of the originally invited 89 grant holders submitted a Background Report for this evaluation. To this came one more grant holder whose centre had been subject to a thorough evaluation in 2004. Documentation from the latter was used as input to the overall panel deliberations. A list of the groups is given in Appendix 2, where the submitting grant holders are called Group Leaders.

The Panel members were given access codes to a special Panel site on the Internet, where all Background Reports had been uploaded. The "panel version" of the reports then had been given a new design, rendering them more reader-friendly than the original version, that was a straightforward printout of the web-based form that the group leaders had filled out.

The Background Reports were peer reviewed by in total 24 international experts (Appendix 5) outside the circles of the Panel. In general each report was sent for assessment by two experts, some to three due to e.g. large groups and/or comprehensive contents (multi-area or otherwise), or in order to have experts review certain separately reported, but somehow related activities together. The number of background reports per each reviewer varied between 3 and 10 depending on area and profile of expertise. Altogether over 130 distance evaluation reports were returned.

The distance evaluators were recruited from among the wide network of experts of the organising bodies, including some who were initially suggested as panel candidates or otherwise recommended by various parties consulted during the planning process.

At the recommendation of the Panel, the results of the respective distance evaluation will be made available to the individual groups. This is because the Panel Report does not go into detail but reflects the charge of the Panel to synthesise and integrate an overall assessment of the position of Swedish Biomedical Engineering Research based on the background material provided.

During the panel visit ten hearing sessions were held at the Swedish Research Council with in total 61 grant holders, leading as many research groups (or departments or units) at 11 different academic institutions – mainly eight universities, but also two university colleges and one research institute. The hearings schedule is presented in Appendix 1.

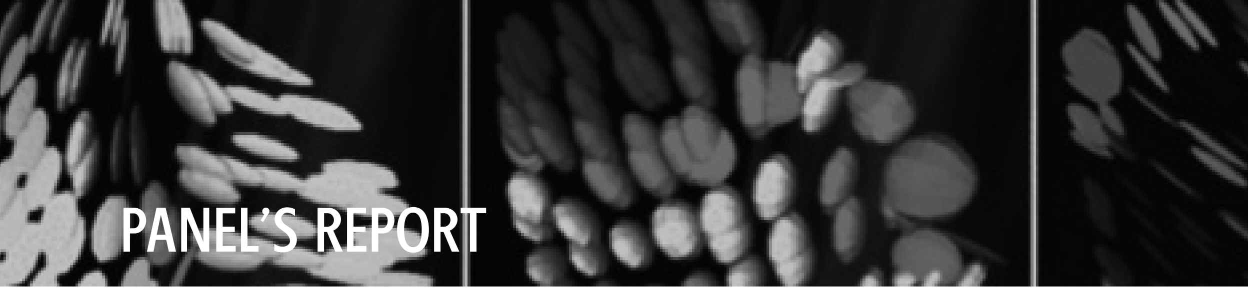
Each hearing session was organised as a number of 15-minute blocks with each leading grant holder giving a 5-minute presentation followed by questions from the panel. The 61 presentations were distributed among the following session headings, for practical reasons grouping together activities from some of the individual sub-areas mentioned above. Some of these ad-hoc headings collected many groups and thus some sessions were "duplicated":

- Medical physics etc 1 and 2 (No. 1 incl. optics)
- Biosensing, microsystems 1 and 2
- Biomaterials, tissue engineering 1 and 2
- Image processing and Information technology; Informatics; Mathematics for BME
- Physiological measurement technology
- Biomedical instrumentation and Signal processing
- Groups associated to the Artificial Hand project (neuro – interface).

Following individual presentations, all sessions were concluded by a joint discussion with all grant holders in the respective sessions. The panel members here brought up a number of issues of cross-cutting and general interest including, e.g.

- Strengths and weaknesses of Swedish research (in BME)
- Collaboration within Sweden
- Strategy for the future / Future directions
- Where can Sweden make its mark?
- Important issues to be addressed
- Career development (incl. gender aspects)
- Training; PhD's vs. Postdocs.

The last two days the panel members spent deliberating and drafting their report.



PANEL'S REPORT

Introduction

In January 2006 an international panel was convened to evaluate the biomedical engineering research supported by the three major funding bodies in Sweden, to assess the state of biomedical engineering research in Sweden, and to look to the future and make recommendations as to how this activity in Sweden might be further enhanced. The convening funding bodies were:

1. The Swedish Research Council represented by the Scientific Council for Natural and Engineering Sciences,
2. The Swedish Agency for Innovation Systems, VINNOVA, and
3. The Swedish Foundation for Strategic Research.

The panel met during the week January 15-21, 2006 and as part of its activities, it had the opportunity to hear reports from 60 different investigators, being supported by the three sponsoring funding bodies, with their presentations organized into 10 different sessions. At the end of each session, there was an additional opportunity to engage in general discussion with the investigators as a group and explore some general issues. The panel also benefited considerably from the peer review of each project by the distance evaluators, i.e. individuals who were experts in specific areas, and who were sent background reports to evaluate and mailed their reviews.

It should be noted that biomedical engineering emerged worldwide in the latter half of the 20th century. From the very beginning it was multidisciplinary in nature, including engineers, life scientists, and clinicians. Although still retaining this multi-disciplinary character, biomedical engineering is also emerging around the world as a discipline in its own right, an engineering discipline based on the science of biology, one that integrates biology and engineering.

In Sweden biomedical engineering also started 50 years ago with a very multi-disciplinary character. Major nucleation points were Göteborg, Linköping, Lund, Stockholm, and Uppsala. There is a Swedish Society for Medical Engineering and Physics (Svensk Förening för Medicinsk Teknik och Fysik, MTF). This society has nearly 1000 members, with only a small minority being university-based researchers. Furthermore, there are many areas of biomedical engineering research as recognized by the international biomedical engineering community where apparently the engineering investigators in Sweden do not identify with the society.

The members of the international panel are listed in the Preface, and a brief bio-sketch of each is included (Appendix 7). The panel is well aware of the fact that it has not seen all of biomedical engineering in Sweden; however, this report is based on the research presented to the panel. If we have overlooked important activities in biomedical engineering in Sweden, we sincerely apologize. In spite of whatever omissions may be contained in this report, we can only hope that the comments and recommendations will prove useful. What follows in the next section is a discussion of the general issues that emerged from the panel's activities.

General Issues

As part of the panel's review of the research projects supported by the three sponsoring funding bodies and its assessment of the state of biomedical engineering research in Sweden, there were a number of broader issues that were brought to the panel's attention. It is these that are addressed in this section.

Biomedical Engineering Research in Sweden:

As noted in the introduction, biomedical engineering worldwide has evolved from a strictly multidisciplinary character 50 years ago to a state where, although this multidisciplinary character is still very much evident, there has emerged a new engineering discipline. This new discipline is one that is not only based on the science of biology, but where there is an integration of biology and engineering. With this integration, new educational programs have emerged or have been established at various universities around the world. A major factor has been the biological revolution that has not only altered the sciences, but also is revolutionizing engineering and engineering education.

While this revolution has occurred in many countries, it was not apparent to the panel that this has also occurred in Sweden, at least not to any great degree. Much of what is presently viewed as biomedical engineering in Sweden is what characterized the field 25 years ago. One Swedish investigator referred to present day activities as "classical" biomedical engineering, a field that historically grew out of electrical engineering. Although in Sweden this view is undoubtedly changing, the emergence of the "new" biomedical engineering needs to be accelerated if Sweden is to be competitive on an international scale.

There are a number of observations that should be noted. To start with, there clearly is some first rate research in biomedical engineering taking place in Sweden. The investigators leading this research and the funding bodies should take genuine satisfaction and considerable pride in this. Second, although there clearly are a number of laboratories successfully focusing on clinical problems and/or interacting with clinicians, in many other cases there were no such interactions. There were even a number of engineering investigators who seemingly had no interest in or did not understand biological questions or clinical problems, only an interest in the technology being developed in their individual laboratories. Third, some investigators had no interaction with industry, while others were too highly leveraged on industry funding for their research support. Fourth, in many cases the research was incremental in nature, with there not being enough high risk, potentially high reward research. One might argue that, if all funded research achieves the stated objectives, then the "boundaries" of new ideas are not being "pushed" to the extent necessary. Finally, there is clearly too little support for biomedical engineering research in Sweden, especially for basic, high risk research, and the result of this is that many investigators are continually "scrambling" for funds, going from one project to the next to merely survive, much less plan for the future.

Academic Structure:

The panel was literally "shocked" by an academic system that appears to not be committed to research, even in the top universities. The panel reached this conclusion based on the fact that senior level faculty received only a minority of their salary from the university budget, the rest being from external research funds. At the most junior faculty level, there appeared to be no career track whatsoever, only "patchwork" approaches with "chance" playing as much a role in success and advancement as much as talent and hard work.

These academic structure issues are not new. In the 2004 report on the Evaluation of Swedish Condensed Matter Physics, the academic employment structure was discussed using the term the "25-50% professor." This report pointed out that many have "little enthusiasm to undertake adventurous or exploratory work" and the difficulty developing "a long-term coherent research strategy." The present panel found the same shortcomings to be true for biomedical engineering. There also are serious problems at the junior level which are not new. In the International Evaluation of Biotechnology published by the Swedish Research Council in April 2003, it was pointed out that a "lack of scientists in the level between PhD and senior PI could lead to difficulty in recruiting group leaders in the future." It goes on to state that "under the present funding regime, younger scientists face two problems: they compete for limited funds with scientists of established reputation, and: they do not have access to the infrastructure available to more established staff." In fact, it appears that in Sweden, the best opportunity for a young person, having completed a post-doc, is to find a senior investigator who will serve as a "patron" and foster their career. Although there clearly are benevolent "patrons", this is not a system that in general empowers young faculty to establish an independent research programme with new directions. As already noted, this point was made in the April 2003 Biotechnology report, and although there now exist a few programs in Sweden designed to address this, the number of positions available is very limited and they do not cover the entire track from post-doc to full professorship. This problem thus remains a significant threat to the quality and quantity of Sweden's research in the future.

There are other issues that were brought to the attention of the panel including the seeming lack of mobility of researchers, a particular concern for young researchers, and the fact that apparently few PhD students, having completed their doctoral work, go abroad and do a post-doc. If they do a post-doc, for the most part it is for only one year, as opposed to the 2-3 years required to do a complete research project of the type that would truly further the training of the individual. In the context of training, the panel was surprised that there were no special "training grants" to provide support for PhD students in research areas of specific importance to Sweden.[1]

Finally, although the Scientific Council for Medicine of the Swedish Research Council was conspicuous by its absence in the evaluation of biomedical engineering that took place, the panel did have the opportunity to meet with a number of physicians active in research. What the panel heard was that in Swedish academic medicine it is no longer necessary for a clinician building a career to be involved in science and in research. Furthermore, although there are exceptions, young clinicians apparently do not have the time to pursue research in parallel to their clinical duties. This lack of cross disciplinary activity does not bode well for biomedical engineering research in Sweden as the clinician-engineer interface is one that this panel believes is critical.

The Building of Bridges:

In today's world the bridging of disciplines is essential to the advancement of science and technology. This is certainly true of biomedical engineering

[1] The term "training grant" refers to a grant from a government to a group of faculty in a specific area of science or technology, where the funds are used to support PhD students.

where there must be a three-way bridging of engineers, life scientists, and clinicians. Although the panel saw occasional excellent examples of interdisciplinary work, it also felt that there were many investigators who were not at all connected to a clinician and the clinical problem, and/or a life scientist and the fundamental biology including the basic biological question being asked. As noted earlier, there were even engineering investigators who seemingly exhibited little, if any, interest in the biological questions or clinical problem being addressed. To address this, funding programs in Sweden that are designed to encourage interdisciplinary activities, ones involving Co – PIs from totally different disciplines, should be expanded.

In Sweden, with exception of Linköping University which has had a Department of Biomedical Engineering for a quarter of a century, the establishment of biomedical engineering degree programs is a relatively recent development. In all of these programs, including those at Linköping, it will be important to include the life sciences in the curricula and to integrate the biology with the engineering.

The panel also noted that many Swedish investigators were heavily involved in European Union (EU) activities, including the EU networks. Although this is to be commended, there in addition needs to be more networking within Sweden itself so as to create an integrated activity with a critical mass and one that can be internationally competitive. It was of interest to the panel that one seemingly effective approach to bringing investigators together has been some of the inter-institutional educational activities that have been supported by the funding bodies.

Finally, in today's world where it is only through the commercialization of technology that one can impact the wide patient population that is in need, bridging academic research to industry also is important. As noted earlier, although some investigators who met with the panel clearly had industrial connections, others did not. One of the roles that biomedical engineering can play is to be the translational component in the process of moving bench top research through commercialization to the patient bedside. This is a role to which the Swedish biomedical engineering community should aspire.

Assessment of Research

In this section an overall assessment of the research that has been supported by the three co-sponsoring funding bodies is presented. The funded projects are discussed and an overall analysis is provided. Integral to this analysis are the evaluations provided by the distance evaluators who submitted reviews by e-mail. It should also be noted that this section has been organized in a manner somewhat different from the hearing schedule. This is because the order of presentations to the panel as reflected in the hearing schedule at least in part was the result of the availability of the presenters.

A Physiological Measurements

Most of the reports on physiological measurements that were reviewed by the panel concerned the cardiovascular system. Based upon the information provided, this area can be divided into the following topics: (1) the assessment of cardiac function, (2) the assessment of tissue perfusion, (3) the assessment of artery wall properties, and (4) the development of cardiovascular measuring devices.

In Sweden there is a long standing tradition in the non-invasive assessment of cardiac function. This includes the determination of wall mechanics, flow velocity distribution in the heart and cardiac valve motion. In Lund, Edler and Hertz made the first non-invasive recordings of mitral valve movement in the world, this as early as 1953. In more recent years sophisticated techniques have been developed for cardiac flow estimation by means of ultrasound, for 3-D representation of the flow field in the left ventricle and the left atrium, and for left ventricular wall motion by means of phase contrast MRI. These developments have certainly contributed to a better understanding of cardiac function in health and disease. Right from the beginning computational techniques have been part of these function assessments and recently modelling and simulation have been included. In the modelling a "Physiome [2]-like" approach is taken, which implies integrated modelling of organ functions, albeit that regarding the heart at present in Sweden only the fluid dynamical and mechanical aspects are considered (see also section E). There also is a recent focus on the non-invasive assessment of wall shear stress in the aorta using MRI and a modelling approach.

In Linköping the expertise in biomechanics (modelling and simulation), imaging, and clinical function assessment (clinical physiologists and cardiologists) has been brought together in one organization: the Centre for Medical Image Science and Visualization (CMIV). The groups participating in CMIV are relatively independent, but there is a common strategy for the centre. Most of the scientists active in CMIV have an extensive international network.

[2] "Definition of the Physiome: The physiome is the quantitative and integrated description of the functional behavior of the physiological state of an individual or species. The physiome describes the physiological dynamics of the normal intact organism and is built upon information and structure (genome, proteome, and morphome). The term comes from "physio" (life) and "-ome" (as a whole). In its broadest terms, it should define relationships from genome to organism and from functional behavior to gene regulation." Source http://www.physiome.org/About/.

Within the country the centre collaborates with the Karolinska Institute and the University of Lund in the framework of CORTECH, which was supported by the Swedish Foundation for Strategic Research to stimulate collaboration in cardiovascular research and training between these centres. The financial support ended in 2004. Several of the CMIV members participate in the Competence Centre for Non-invasive Medical Measurements (NIMED), which is supported by the university, industry and VINNOVA. There are also extensive collaborations with industry.

At the Karolinska Institute an improved and more quantitative technique has been developed to assess strain in the ventricular walls by means of ultrasound. Some of the initial problems have been overcome, which makes their approach interesting because of the better spatial resolution of ultrasound as compared with MRI. This group has extensive collaborations, but mainly in Sweden. There are well established collaborations with industry. New algorithms to analyze the dynamics of atrial fibrillation in patients have been developed in Lund. The pharmaceutical industry has shown interest in this development for the testing of drugs in this disorder. For further details the reader is referred to part E of this section.

Sweden also has a longstanding tradition in the assessment of tissue perfusion, especially skin perfusion, by means of Laser Doppler techniques. It was one of the first countries where Laser Doppler instruments for clinical applications became commercially available. In the course of developments more attention is paid to the light-tissue interaction and its effect on Laser Doppler flowmetry. Emphasis is on better quantification of flow velocity measurements. Scientists active in this field are also exploring other areas in biomedical optics, i.e. the assessment of perfusion and oxygenation of the beating heart. This will especially be applied to the patients in the intensive care unit. The perfusion assessment is still at an experimental stage, but the first measurements on myocardial oxygenation in patients have been made. Optical techniques also are used for navigation in stereotactic and functional neurosurgery as part of the approach to minimally invasive diagnostics and therapy.

In Linköping, these activities are concentrated in the Department of Biomedical Engineering. Three groups are active in the department with partially overlapping activities. Most of the plans of these groups are clear, but often follow an incremental approach. Some ideas are more difficult to rate at their true value. Although there are some differences in interest, the question can be asked why these groups are independent, because the basic technologies used by the participating scientists are quite similar. Moreover, they publish jointly. Could not joining forces make them a stronger group? The groups do have international collaborations and cooperate with industry. Several of their developments have been commercialized by a Swedish company.

Another approach to the assessment of tissue perfusion is being pursued in Lund. This involves using contrast agent MRI to image brain perfusion. For further details the reader is referred to Part B of this section.

The non-invasive assessment of artery wall properties by means of ultrasound has become an increasingly important method in vascular studies and in patient management. The group in Lund is working on a 2-D approach to determine artery wall dynamics. Their approach does not only take into account radial displacements of the artery wall, but also displacements in the longitudinal direction. This group participates in CORTECH. The group has some international collaboration, but as far as can be judged not any with industry. The group at the Karolinska Institute has also applied their ultrasound technique (see above) to the assessment of strain in the artery wall.

Several groups are active in developing techniques that can be applied to evaluate cardiovascular function. Beside the assessment of strain in heart and arteries as described above, the well established group at the Karolinska Institute, among others, has developed a catheter to determine pressure/volume relations in cardiac cavities, a long term implantable pO_2 sensor to be integrated into commercial pacemaker systems to improve demand pacing, and a mobile tomographic gamma camera system. The catheter is different from the commercially available types because it uses 4 rather than 12 electrodes to assess volume by means of the conductance method. The group has an extensive network of collaboration, but mainly in Sweden. There are extensive contacts with industry.

The relatively young group in Västerås focuses on the development of wireless, wearable sensors to assess physiological function. So far they have developed a system combining ECG and heart sounds, to be combined with blood flow measurements at a later stage, and a method to determine CO_2 in expired air through a resonant sensor. The group collaborates with centres in Sweden and abroad and extensively with industry.

The group in Linköping has developed, amongst others, an intelligent stethoscope to detect heart and lung sounds, making use of new signal processing algorithms, a photoplethysmographical method to non-invasively determine blood pressure, and a bio-optical method to quantify waste product elimination in dialysis, the latter in close collaboration with an industrial partner.

Also, the Royal Institute of Technology in Stockholm has developed a very small catheter-tip micro manometer, which is a commercial success.

A group in Borås, that has just started, is aiming at developing techniques to early detect dementia and to monitor the elderly in the home situation. The ideas of this group have not yet been fully developed.

Sweden has a longstanding tradition in the non-invasive assessment of cardiovascular function by means of ultrasonic and optical techniques, and more recently by MRI. Sweden was at the forefront of the developments in this area and the activities in Sweden have made major contributions to our understanding of mechanisms underlying cardiovascular diseases. This position was gained due to an innovative way of thinking and good collaboration between (biomedical) engineers on the one hand, and clinical physiologists and clinicians on the other.

When evaluating the present situation, one has to come to the conclusion that much of this entrepreneurship has disappeared. The research performed is generally solid, but incremental without taking risks, having less international impact than in the past. There are only a few ground breaking areas. The most likely explanation for this relatively dramatic change is the limited funding on a more long-term basis, hampering the development of real new ideas. Therefore, scientists have to rely on quick developments which are frequently based upon existing technologies. Examples are the developments in the area of Laser Doppler flowmetry and the development of cardiac catheters, an intelligent stethoscope, and sensors to measure blood gases. Also, most of the developments in vascular ultrasound are incremental, both in the assessment of intima-media thickness (IMT) and of artery wall properties. It appears that there is not much opportunity for basic, high-risk research in this area.

Very good to excellent developments are taking place at CMIV in Linköping, where an internationally competitive program on cardiac function has developed. This ranges from basic biomechanics, including modelling and simulation, to the development and use of sophisticated ultrasound and MRI techniques to study cardiac function in volunteers and in patients. The intensive collaboration between mechanical and biomedical engineers, clinical physiologists and cardiologists makes this centre a success. The new approach to the non-invasive assessment of wall shear stress in the human aorta and the integrated modelling of cardiac function indicate that the scientists have the opportunity to catch up with international developments.

Also, at the Karolinska Institute some very good, internationally competitive work is ongoing. Specific areas include the improvement of demand pacing by incorporating pO_2 sensors in the pacemakers, the assessment of myocardial strain by means of ultrasound, and the development of mobile tomographic gamma camera systems.

Worth mentioning are the developments in Linköping, where their optical expertise is being used to develop new techniques to estimate radio-frequency lesion size during brain surgery and for navigation during stereotactic and functional neurosurgery. The latter application is of great importance in this era of minimally invasive diagnostics and therapy. This research is of very good quality.

The review panel was surprised that in the cardiovascular area barely any reference was made to cardiovascular risk assessment or to the early detection of cardiovascular disease. These are important areas of research around the world. Only IMT is used as a marker of atherosclerosis and some initial attempts are made in early plaque detection by means of ultrasound rather than by MRI! It also was surprising to see that some important work was being done by engineers without a strong collaboration with biologists or medical doctors.

Finally, in Sweden, there appears to be no real strategy for coordinating and stimulating the area of physiological measurements on a more structural base. An attempt was made with CORTECH, in which the research activities and the PhD-training programs in Linköping, in Lund, and at the Karolinska Institute in Stockholm were intended to be brought together. This initiative has lead to a joint teaching program for PhD students and the beginning of research collaboration. The funding of this centre, however, has ceased, and those who had participated appear to have no joint strategy in research. This is to be regretted because research in small countries, such as Sweden, will benefit from collaboration and coordinated research activities between good quality centres. Such a strategy will greatly strengthen Sweden's ability to withstand the international competition. Also, more emphasis should be placed on risk assessment and the early detection of disease. Based upon the expertise on non-invasive assessment of cardiovascular function in Sweden, it must be possible to develop new strategies in this area. In this respect, molecular imaging has to be mentioned, a booming area internationally, and yet the panel heard little about this in relation to biomedical engineering activities.

B Biomedical Imaging and Medical Physics

The research in medical radiation imaging being covered here is by investigators at the Royal Institute of Technology (KTH), Uppsala University (UU), Lund University (LU), Linköping University (LiU), and Chalmers University of Technology (CTH).

The research includes the development of refractive X-ray lens including: a multi-prism X-ray optical system; a dual-energy photon counting scanned-slit digital mammography system; and electronic data read-out for radiation therapy portal imaging systems. A significant amount of software for the detection of local cancers also has been developed.

Another area of research comprises work on a liquid-jet-target laser-plasma source. This uses soft X-rays and the extreme ultraviolet (EUV) energy range. Another development consists of a compact X-ray microscope with sub-visible resolution and liquid-metal-jet anode electron-impact source using hard X-rays. This group also engages in confocal microscopy for the measurement of intracellular parameters and the investigation of the optical system of the human eye. The aim is to improve peripheral vision and the understanding of central visual field loss. Ultra-sensitive biochemical materials are being analysed by combining ultrasonic trapping, with modelling of the biochemical processes and fluorescence microscopy.

Other areas of research involving digital X-ray imaging comprise the development of simulation tools, such as Monte Carlo techniques, which require GRID computation - as well as a hybrid pixel detector consisting of semiconductor chip and electronic chip for dynamic X-ray imaging.

Yet another area of research involves the use of fluorescent methods. Two specific areas were described: (i) molecular imaging systems to measure optical properties for diagnostic and photodynamic therapy utilizing fluorescence spectroscopy for measurement of absorbed and scattered spectra; and (ii) laser-induced fluorescence for optical mammography and early cancer detection.

Work is being undertaken on Laser Doppler Flowmetry (LDF) and video assisted microscopy. This includes: light modelling using Monte Carlo techniques and liquid optical phantoms with specified optical properties; oblique angle illumination and diffused white light spectroscopy.

CT techniques are being applied in the area of forensic medicine for the purposes of virtual autopsy at post-mortem. A mixed reality environment has been created for the surgeon by the fusion of CT, MRI and optical imaging.

Other research involving X-rays includes: digital X-ray projection radiography including detector characteristics such as MTF, noise power spectra; and DQE. The simulation of X-ray transport from source to image receptor; Tomosynthesis; Micro CT, 3-D imaging with computational models, methods for assessments of image quality, observer models, reconstruction algorithms for Cone Beam CT, and creation of hybrid images are all other areas of research.

Microwave methods have been developed for tomographic studies of the breast, hypothermia and hyperthermia applications. In this context, dosimetry, mobile phone dosimetry and exposure, and low frequency exposure (e.g. welding machines) are also being studied. Research performed by this group is very good.

In the area of medical radiation imaging with therapeutic intent, research at the Karolinska Institute's Center of Excellence for Radiation Therapy (financed by VINNOVA) ranges from basic work to clinical implementation, with the potential to produce commercial products. Results from research performed in this Centre are published in high-ranking journals and the publications are among those most frequently referenced in the field. The standard of research at this centre, both in quality and quantity, is excellent. Therapeutic radiation research at the Centre includes: research on radiation biology, with modelling at the cellular level; the development of a new clonogenic cell survival model, which incorporates the concept of conditionally repairable damage in the linear-quadratic cell survival model; hypoxia and modelling of dose-toxicity relationships - as well as modelling of clinical data; the development of a 1200-lymph node atlas; molecular finger printing (starting from single cell); and the use of genetic make-up of patient in radiation treatment. Other areas of research involving therapy include radiobiologically optimized treatment planning algorithms - such as Intensity Modulated Radiation Therapy (IMRT) with narrow pencil beam scanning of high energy photon - and electron beams that incorporate optimization software with biological conformity. Another area of work comprises the measurement of dose distribution in the patient using high resolution PET-CT imaging, as well as to determine dose distribution to the tumours and the organs at risk by PET/CT and PET/MRI methods.

Not yet covered in this sub-section is the development of radiation detectors, including a proprietary scintillation compound with a detector that is based on gas electron multipliers (GEM) for use in PET cameras. Patient positioning for therapy using precision and image-guided radiation treatments is now being achieved by a laser scanner for motion gating and adaptive therapy with sub-mm resolution.

Some of the non-radiation research areas in biomedical imaging that were covered by investigators at LiU, CTH, and LU include (but is not limited to):

MRI quantification of atherosclerosis (using 1.5 T MRI whole body) to measure thicknesses of vessel wall; creation of databases to look at MR spectra of metabolites; magnetic stimulation for neurogenesis; patient modelling for epilepsy studies, brain monitoring, functional techniques such as perfusion maps using dynamic susceptibility contrast agents, diffusion using fibre tracking linking diffusion to MRI (Q-space imaging), fMRI (motor activation in tumour patients) and Spectroscopy (MRS), both non-ionising radiation and non-invasive methods were used to differentiate benign vs. malignant tumours.

Some investigators presented signal and image processing methods. Techniques based on the fast Padé transform (FPT) were described in relation to retrieving undetected data from MRI and Spectroscopy (MRS) (KI). The argument is that the method extracts diagnostically important quantitative information which cannot be detected by the FFT and gives improved S/N, with stable convergence and robust error analysis. However, for the applications presented the FPT was 50% slower than the FFT. The technique is currently being used to differentiate benign from malignant tumours using MRI. In

MRS the FPT specifies the number of metabolites and provides more quantitative information. Research performed by this group is very good.

A significant amount of research is being carried out on the development of systems for medical image analysis (e.g. MR, CT and US) in e.g. Linköping and Uppsala. A significant amount of the work focuses on theoretically advanced methods for volume and volume sequence processing and is working towards unified advanced mathematical tools. Important areas are tensors, manifolds, mutual information and canonical correlation. Filters for 3-D and 4-D analysis are 100 times faster than standard filters. A typical application is fibre tracking in the brain. The research also includes work on discrete geometry and 3-D shape analysis from tomographic data, as well as basic research on segmentation, watershed, digital geometry, and multivariate analysis.

Fundamental work is being undertaken on the mathematical modelling and numerical simulation of brain systems and functions; this has been ongoing over a 10 year period. Areas of application include modelling spinal locomotors functions of vertebrates, the neuroendocrine system, and simulating normal and disease states such as Alzheimer and diabetes. Models of biochemical systems thermodynamics, membrane biophysics and multi-component Hodgkin-Huxley have been built using networks of coupled ordinary differential equations. (See also section E below.)

Also in the area of brain imaging etc, volumetry techniques, based on MR images, are being developed in relation to the hippocampus: these include reliable manual methods for segmentation of the hippocampus, estimation of intracranial volume (ICV) and the use of multi-planar scans. Matched filter techniques were also being developed, based on a new non-rigid method (the Morphon).

Fractal techniques are being developed to determine the fractal spectrum from the retina of the eye. Similar techniques are also being applied to Mammography (Umeå).

There is a considerable amount of work on the application of medical ultrasound to the quantitative image analysis of atherosclerotic plaque. This includes the assessment of the mechanical properties of plaque, including stable and non-stable, as well as soft and hard plaque (e.g. Chalmers). An image analysis package, comprising boundary identification using dynamic programming, is being used by 30 laboratories (20 in EU, 10 in USA).

Substantial evidence was presented that there is outstanding scientific research in the area of *radiation biology* and *medical radiation* imaging with therapeutic intent at the Karolinska Institute. The Centre of Excellence for Radiation Therapy is one of two outstanding centres in the field in Europe (the other one being DKFZ in Heidelberg). The Centre is now taking a leading role in image-guided radiation treatments. The scientific endeavours range from basic research to clinical implementation, with the potential to produce commercial products. There is also extensive evidence of technology transfer and commercialization at this Centre.

In addition, there is a considerable amount of research in the area of *diagnostic medical imaging*. This ranges from direct application of MR, CT, US etc to various areas of clinical application, as well as fundamental studies relating to the development of new and improved imaging techniques, and fundamental modelling studies. Quite a lot of the research is of high quality and reflects international trends. A number of the groups are well established and are, for example, involved in EU projects and Networks of Excellence, as well as wider international collaboration.

It is important to note that a number of groups are currently working mainly in isolation. Their main links seem to be to local clinicians. This is entirely acceptable if the work is then presented at national and international conferences, as well as being published in leading international journals. There is some evidence that this is not happening in certain areas, with the result that good work goes on which replicates similar work in other international centres. Therefore, it is important that new ideas and new areas of research be fostered; these often arise from the work of a single individual. Hence, there must be a balance between group research which is part of the international scene and developing new areas.

There is extensive evidence of the development and application of signal processing techniques, particularly in relation to MRI and MRS applications. Internationally MRI and MRS are large and important fields with many research groups involved at all levels. One area of the research presented during the review focused on the development and application of Padé spectral methods (FPT). This may be an important development, but the FPT was compared with the FFT. What is not clear at present is how the FPT compares to more normal short term spectral estimators, e.g. based on AR and ARMA.

More general research is being undertaken on MR, CT and US. There is quite a wide spectrum of activity that ranges from mathematically based analysis of the modalities and procedures, 2-DF and 3-D segmentation, reconstruction to filtering. The international standing of much of this work is clearly recognised. The majorities of the research groups involved have built substantial international reputations over many years and are involved in a range of international projects and consortia.

In general, the standing of the groups in therapeutic medical radiation imaging and those involved in MR, CT and US imaging is good. Individual projects seem to be well run. However, it was not always clear if the projects were part of a broader overall strategy in relation to specific longer term programmes relating to the various modalities. It would appear that there needs to be greater awareness within the Swedish groups of what work is underway and planned. This need not necessarily take the form of specific collaboration; but, for example, a series of fairly regular joint meetings in the form of one day workshops could be a very useful development. In the specific area of medical imaging it would be worth establishing (i.e. funding) a joint research initiative (JRI). This would comprise a competitive bid across the country. Typically, three or four groups in different universities could form themselves into consortia and make a joint bid. Such a JRI programme should be for a period of five years with reviews at the end of the first, third and fifth years. Within the programme provision should be made for PhD students and Postdoctoral Fellows.

C Biosensors, Microsystems and Lab-on-a-Chip

The development of biosensors over the last 30 years has resulted in a diversity of new analytical formats, including those with applications in environmental sensing, drug discovery, animal health care, clinical diagnostics and industrial processing. Within the last decade, advances in microengineering, particularly those focused in microfluidics has seen the miniaturisation of biological sensors and instrumentation into "Lab-on-a-Chip". This technology now offers the potential for sample preparation, as well as more rapid and highly sensitive analysis in a low cost format. At the same time, microsystems technology has offered the prospect of automated biological sensors being connected as free-standing wireless networks, comprising distributed sensors. It has been envisaged that these may be linked directly to clinical information systems to provide decision support to the patient or doctor.

In parallel with these developments in analytical sciences and engineering, there has been much activity in the field of bionanotechnology, where there has been a particular focus on the tailoring of the biosensor interfaces, thereby improving the efficacy of the sensor. Nanotechnology has provided other significant opportunities in biomedical engineering, particularly in the field of materials science, where new functional materials are being produced, which may ultimately improve implants and prostheses. In the context of biomedical engineering, one additional area of importance lies in the area of producing functional nanoparticles, which may have diverse applications including those as contrast agents in imaging, for drug delivery, and as functionalised sensors (where the unique optical properties of the sensor may be exploited).

Sweden has a long tradition of industrial research in the field of biosensors (focused through the "Biacore" platform), and more recently Lab-on-a-Chip (especially through the Gyros CD platform). This commercial activity has traditionally been supported and complemented by strong academic groups, focused on both fundamental and applied research. The panel was able to review an extensive list of 10 groups of researchers, with many examples of biosensor and Lab-on-a-Chip projects being presented from the Universities of Lund, Chalmers, Linköping, KTH and Karolinska. In addition to those investigators that were able to present evidence of Sweden's strengths to the panel, it was also noted that there are many other internationally recognised Swedish scientists working in the general fields of biosensors and Lab-on-a-Chip who were not included in this review. The primary reasoning that these experts were not included in this review appeared to be that although they have projects supported by one or more of the three funding bodies sponsoring this evaluation, their principal activity was financed under other headings, e.g. in biotechnology (with potential applications in drug development, etc), rather than in biomedical engineering.

The traditional strengths of Sweden in instrumentation science and engineering were apparent in many of the groups that presented information to the panel. For example, in Chalmers there has been a considerable effort on the development of a new sensing modality based on the quartz-crystal microbalance. This work has resulted in a label-less technology, which not only has applications in the characterisation of biological interfaces, such as supported lipid bi-layers, but can also be used as a biosensor for diagnostic sensing. Similarly, at both KTH and at the University of Lund there was ample evidence from groups within both Biomedical Physics and Electrical Measurement Technology of scientists and engineers using advanced analytical methods, including those based on electrohydrodynamic flow of cells generated both by dielectrophoresis and ultrasound in order to manipulate samples within microfluidic channels. Two particular examples were seen, where it has been possible to establish a high sensitivity analytical platform (with limits of detection of 50 fM) in KTH and in the development of a method of processing post-operative blood, removing fat from patients blood without haemolysis at Lund. Finally, within the field of microsystems, there was evidence of an extensive and internationally recognized activity from within KTH covering the fields of MEMS design and microsensor development, as well as Lab-on-a-Chip technologies. In all of these activities described above there was a clear academic structure to the groups, with young scientists being fostered and supported. All of the groups were seen by the external (distance) evaluators to have strong track records in academic journal publication and patenting. The (BME-related parts of the)

Microsystems groups at KTH, Lund and Chalmers also had been successful in commercialisation of their technologies, ultimately leading to company spin-outs and economic creation.

Other examples of biosensor research, both from Linköping and the KTH-KI focused on the development of new nanotechnologies as sensors for probing biological activity either within cells or in pre-clinical studies in-vivo. The work at Linköping is based upon a highly innovative class of polymers which can be taken up by the cell. The group has used these molecules as sensors to decorate biological ligand binding molecules, such as calmodulin. It has been shown that the optical properties of these sensor molecules can change dramatically when the molecule is sterically modulated (as a consequence of biological ligand binding). Likewise, in the KTH-KI group, a series of nanoparticle technologies have been produced that have been used as sensors in vivo.

Work was also presented in applications oriented research from a second group in Lund, in which microbiosensors were fabricated and used by medical groups to study disease models in neurobiology. This aspect of biosensor research was praised by the external evaluators, and the panel was greatly impressed by the motivation of the principal investigator. Indeed, both of these latter groups, at Lund and KTH-KI, had an impressive track-record in gaining funding from the EU and the far-East, clearly providing an international benchmark for their research.

A third group from Lund presented their work in biosensing platforms, covering a broad range of topics including thermal biosensors as well as new developments in nanoscale science. They will clearly benefit greatly in the future through their planned interactions with both micro and nanoscale scientists, and it is to their credit that they have recognised this need, and already acted upon it.

Overall, it was seen that there was less academic research presented in the field of biosensors that showed genuine interaction with clinical and-or biomedical departments, where the efficacy of diagnostic measurement could be established. However, it was noted that when technologies reached a stage where they were to be commercialised, there was more evidence of biosensor groups working with clinicians.

Microsystems, instrumentation and Lab-on-a-Chip work was found to be at the international state of the art, with innovative research being developed from the bench all the way through to commercialisation. Similarly, within the field of biosensors, there was evidence of an extensive infrastructure comprising well funded academic groupings working across the whole field, and including optical, electrochemical and thermal transduction mechanisms. All of the Lab-on-a-Chip and biosensing groups had demonstrated an ability to win international research contracts, and many of them had developed their products as successful commercial devices and instruments.

It is now well established that biosensor technologies have the potential to offer the opportunity for greatly simplified analysis, providing innovative methods for the collection of remote and-or home based data. The theme of integrated diagnostics, with technology extending from the patient to medical informatics and decision support tools via wireless links is recognized internationally as important, and yet, despite Sweden's strengths in mobile communications, there were no examples of biosensor groups seeking to interact with those involved in wireless research.

The panel saw only one example of research in the fields of in-vivo or implantable biosensors, in which long term animal studies were performed using an oxygen electrode (i.e. as a biological sensor rather than a biosensor). There also appeared to be a lack of research in the field of DNA sensing for rapid assessment of viral or bacterial infection. Such technologies may be of value in acute disease diagnosis and in accident and emergency situations, where time may be critical. Within the field of biomedical engineering, there is a need for the biosensor community to engage more broadly with clinicians involved in biomedical research to form truly multi-disciplinary groupings. These groupings should look to form new research themes.

D Biomaterials and Tissue Engineering

Biomaterials are essential components of both basic research and applied research within the discipline of biomedical engineering. A significant amount of resources have been, and continue to be, devoted to the study of biomaterials in Sweden. There is a long history of successful commercialization of materials for orthopaedic, oral maxillofacial and dental applications. These areas have been historical strengths within Sweden and continue to be a source of considerable revenue through industrial contracts in Göteborg, Linköping and Lund. However, little research activity exists in the discovery of novel biomaterials or the in-depth investigation of alternative materials for biomedical engineering applications or tissue engineering applications. Impressive but isolated efforts exist to address the important areas of host – material interface phenomena (Chalmers and Uppsala) and the surface modification/functionalization of traditional biomaterials (KTH), but these efforts are unlikely to make significant contributions to the field unless supported as major initiatives. The most productive work in the field of biomaterials research is represented by groups with strong clinical associations and these efforts appear to be geographically regionalized within Sweden (Göteborg).

Research in Uppsala addressing the host immune response to implantable biomaterials fills a niche that is relatively unexplored in the field, and this excellent research could lead to important findings.

The potential exists for Sweden to position itself as an international leader in the field of biomaterials research, but fundamental changes will be necessary in the commitment of research funds, the implementation of strategic initiatives for discovery and innovation, the interdisciplinary structure of research teams, and the training and development of the next generation of scientists in this important area of biomedical engineering.

The activities of historical strength as noted above continue to be a source of revenue through industrial contracts with international orthopaedic and dental device companies for scientists still engaged in this activity, especially at the University of Göteborg. These activities, in large part, represent the downstream effects of discovery work in the area of osseointegration by Brånemark several decades ago. These efforts, by necessity, are associated with strong clinical research programs (i.e. Lund, Linköping and Göteborg). However, in spite of the revenue stream generated by this continued activity, there is a need to develop an infrastructure for the discovery of the next generation of biocompatible implantable materials, and a need to expand the focus from bone and oral maxillofacial applications to soft tissue applications.

There is clear recognition of the importance of host cell – biomaterial surface interface phenomena. Expertise exists within the Swedish biomedical engineering community, especially at Uppsala and Göteborg, to make this a notable strength area if appropriate and sustainable resources are made available. These institutions have the necessary intellectual expertise and either have or have access to the in-vitro and in-vivo (preclinical) study laboratories necessary. Educational outreach programs, inter-institutional collaborative efforts, and involvement of the international scientific community through exchange programs and participation in international meetings could propel this activity to a leadership position.

The effects of biomaterials upon individual cells, tissues and whole organisms have important implications for not only biocompatibility and safety reasons, but also for advancement of the field of tissue engineering/regenerative medicine. Research programs addressing these issues exist at Göteborg (Chalmers and GU), Uppsala and Lund and can be considered among the real strengths of biomedical engineering in Sweden. These research efforts have provided additional opportunities including the investigation of the effects of biomaterials upon the attachment, migration, proliferation and differentiation of various stem and progenitor cell populations, an important field of research activity. In addition, in vitro model systems to investigate the effect of mechanical forces upon cell activity have been developed and are likely to contribute to the understanding of stem cell development and differentiation. Investigators at Chalmers have identified this as important and are developing programs to capitalize upon this opportunity.

Finally, a small but important research effort exists in Uppsala to better understand the effects of biomaterials upon systemic immunity. Although this activity is limited, it is relatively unique in the field and provides an opportunity for Sweden to be recognized as a centre for this island of intellectual activity.

There is a notable absence of investment and research activity in the discovery of novel biomaterials; instead efforts and resources continue to be directed toward making incremental improvements of existing biomaterials (e.g. titanium, polylactic – coglycolic acid). Although research efforts exist in the development of degradable biomaterials such as chitosan, alginates, cellulose, purified collagens, and extracellular matrix, the amount of research directed toward these emerging materials is inadequate to achieve or maintain a leadership position in the scientific community. The work of the laboratories in Chalmers and Uppsala is excellent, but would benefit from collaborations within Sweden (e.g. KTH, Lund and Linköping) and with international counterparts in the field. Currently, the critical mass of investigators needed to aggressively investigate these biomaterials from benchtop to bedside does not exist.

Aside from the contract testing work for orthopaedic and dental implant companies, biomaterials research in the present Swedish biomedical engineering community is typically limited to in-vitro testing, with the exception of the laboratories at Uppsala and Göteborg. There is a relative lack of in-vivo testing to address important issues of safety, efficacy and biocompatibility when new biomaterials or functionalized surface coatings of more traditional biomaterials are being investigated. This type of work is a necessary step in the translation of new findings in biomaterials research to the human clinical setting and thus eventual commercialization.

Sweden remains among the world's leaders in the testing and evaluation of orthopaedic and dental implant materials; however Sweden is lagging in the discovery and development of novel biomaterials for biomedical applications, especially in naturally occurring biomaterials. Although the country has limited activity in tissue engineering/regenerative medicine compared to the international community, it has the component parts to grow this area if efforts are appropriately organized and funded.

Investment of resources in the discovery of novel biomaterials for biomedical applications is badly needed and should be prioritized. Without such an investment, opportunities for expansion of existing laboratories and the formation of new laboratories, and the development of a critical mass of both young and experienced scientists in the field of biomaterials, simply will not occur. Such activity is also important to keep Sweden active and prominent in the fields of biomaterials and tissue engineering. Permanent non-degradable biomaterials such as those traditionally used in orthopaedic surgery and dentistry have been, and continue to be, a significant source of revenue in Sweden. Industrial partnerships should continue, but will/should hopefully progress toward more "discovery" work and less "testing" work.

E Other Areas of Research

In addition to the areas of research discussed in the earlier parts of this section, the panel was provided reports and heard presentations on projects in other areas. The areas included here range from biomechanics to hearing aids to electronic health records. There thus is a variety of different areas, and it is these that are discussed next.

One general area that, although a large activity worldwide, is relatively small in Sweden, is that of biomechanics. Three different activities were brought to the attention of the panel.

One of these was mentioned in section A above and involves the modelling of cardiac function by a group at Linköping University. This effort is focusing on the modelling of the mechanics of the heart including the flow dynamics. Although apparently not yet extended to a "physiome" type approach that includes modelling at the cellular and molecular levels, the investigators are interacting with others in this area around the world and doing very good work.

There also was a project presented by a group at Lund University that focuses on fundamental fluid dynamic studies, including using the concept of differential diffusion. The relationship of this approach to the biology and pathobiology, e.g. atherosclerosis, has not yet been clearly developed.

In addition there was a third project that fell within the general area of biomechanics. This was a project by a group at Uppsala University that is developing a method for the analysis of human motion that can be used for clinical applications. The approach is one based on not using markers, and in this application the patient walks along a pathway and gait information is recorded by video cameras and force plates. The work, involving engineers, biologists, orthopaedic surgeons and neurologists, is basically good. It is claimed that the approach is leading to better methods for assessing human motion analysis to improve diagnosis and follow-up, following surgical treatments (orthotics, prosthetics and rehabilitation); however, the impact of this approach remains to be seen.

An important area for biomedical engineering as the field moves into the future is systems biology and modelling that integrates across the biological scales. Thus the initiative taken to start a program on integrative modelling of the nervous system at the Royal Institute of Technology in Stockholm (see also section B above) is challenging, but very much in line with international developments. The group has the expertise to accomplish the modelling, but the endeavour will only be a success if they join stronger forces with biologists, especially to select the biological data to be included in the models.

In the area of signal analysis, there is a project focused on the analysis of cardiac rhythm disturbances with emphasis on atrial fibrillation (e.g. Lund; see also section A above). The approach taken is based upon short-term spectral estimation methods. Also, from a signal processing standpoint research has focused on the use of heart rate variability (HRV) techniques and how ectopic beats affect the HRV signal. A range of techniques are being developed which are based on short-term spectral estimation methods, as well as wavelet transforms. Clinical application areas include assessing the effect of anti-arrhythmic drugs. The research on ECG analysis and associated matters was in itself of a good standard. However, in the area of HRV analysis there is a large amount of international activity. Success in this field is dependent upon groups finding a novel approach to an important clinical or physiological problem.

There is a considerable amount of successful ongoing research in the general area of the analysis of hearing (i.e. basically audiology), and the development of improved forms of hearing aids. The research of various groups in these areas (e.g. Linköping, Chalmers, KTH) is already pretty well integrated and has been ongoing for a considerable period. Another feature of the research is close collaboration with industry (particularly the Danish industry, which is strong in this area). These groups were responsible for the development of the first hearing aid with extensive digital signal processing. Fundamental studies have been carried out on noise induced hearing loss. This has involved the development of detailed computer simulations of hearing loss and hearing aid simulation. New devices are being developed based on bone conduction and more traditional approaches. The research on hearing was well organised and the researchers had a good understanding of the international scene in their field. They also have been working for a number of years with commercial hearing aid companies.

Another interesting area of work comprised research into cochlear implants. A considerable amount of research has been carried out in this area. What was impressive is that the work covers both a detailed physiological study and pretty sophisticated computer modelling of the cochlear and cochlear function. Issues such as the number of channels required for an effective implant had been considered in some detail. The work has now led to the development of a full implant with the potential for commercialisation.

There also is a fifteen year effort by scientists at Lund that has resulted in prototypes of an artificial hand. This research effort has been largely successful because of the interdisciplinary approach of the engineers, physicians and cell biologists involved. Although accomplishments have been impressive, a significant amount of work remains to be done to take this device to the clinic. Integrated circuitry with "learning" capability has been developed and partially tested, and the eventual goal is to develop a "thought controlled" system. The rate limiting steps in further development of the hand appear to be primarily on the biologic side. For example, in vivo studies (both acute and chronic) are needed to evaluate the safety and biocompatibility of implantable electrodes. Interesting work to study the interface between neurons and metal surfaces (e.g. computer chips) is currently being conducted, but what is required is a much more in depth investigation. The problems remaining to be solved are nontrivial, and this group may benefit from collaborative efforts with others in the broad BME community, including materials engineers, systems physiologists, and information technology specialists.

Finally, there is a considerable amount of research in Linköping that is ongoing in the general area of electronic health records (EHRs). This is based on extensive research in medical informatics in relation to this area. Much of the research involves interface terminologies and boundary problems in the relation to the EHR. Ontology research is also ongoing, particularly in relation to SNOMED and other similar systems. This work relates to the higher levels of the human organism (i.e. systems, viscera, tissue) and not, at present to Omics data. Data mining and Decision Support (data driven decision support, as well as canonical correlation analysis and neural networks for data mining) are other areas that are being addressed. Home health care applications are also being covered, e.g. systems for distributed data capture and the virtual patient record.

In the specific area in which they work, research on EHRs in relation to Ontologies, the group at Linköping is certainly internationally recognised. What is less clear is to what extent this work extends into more general research on advanced clinical information systems. From the limited amount of information provided during the evaluation, the work on home monitoring is either at an early stage or not very sophisticated in relation to other groups working internationally in the field.

In terms of the research groups that were evaluated, the majority of the work was of a good standard and progressing along the right lines. It was also clear that the groups were aware of the international research scene in their respective fields. However, in some cases, but not all, there may be a problem of critical mass. This is difficult to assess because an individual group may comprise a significant number of research workers and be part, for example, of an EU Network of Excellence.

The biomechanics work by the Linköping investigators, including the clinical interaction, is viewed as being at an internationally competitive level. The importance of the research on gait analysis hinges on the fact that the approach is one of marker-less recording. Similar gait systems which use markers have been available for a number of years and are sophisticated in terms of recoding and analysis – indeed some are successful commercial products. For this panel the added value and thus importance of the marker-less approach is unclear.

Future Research Directions

With all that is going on in Sweden, including the considerable excellent research being carried out, there is a need to prioritize investments in biomedical engineering research for the future. In this section the panel identifies seven areas that it considers to be of high priority.

Biomaterials:

It is recommended that resources be invested in the development of alternative materials to traditional metals and polymeric synthetic biomaterials, specifically in those biomaterials that are naturally occurring such as purified collagens, chitosans, alginates, hyaluronans, and extracellular matrix that are presently being developed for clinical applications in many fields. Biomaterials research must progress beyond bench top and in-vitro cell culture studies into in-vivo models. This work would logically include preclinical animal models and eventually human clinical trials.

Biosensors:

There are three important areas which, based upon the evidence received by the Panel, appear to be under represented. These are DNA diagnostics, integrated sensors, and in vivo monitoring. For research in DNA diagnostics, the focus should be on a rapid technology for the measurement of real clinical samples, with a team that ranges from microfluidic investigators to clinicians involved in the assessment of diseases such as meningitis and MRSA. The research in integrated diagnostics should involve forming cross-disciplinary teams that include individuals with skills in biosensors, lab-on-a-chip, medical informatics, decision support, wireless communication, power management and system-on-a-chip technology. For research in either in-vivo or implantable sensors, the biosensor community should seek to form links with those involved in biomaterials and tissue engineering to better understand how sensors could be developed that will be able to perform continuous real-time measurements.

Clinical Information systems:

Clinical Information Systems (CISs) are becoming an important area of research. The traditional approach to medical information systems is to divide such systems into Electronic Health Records (EHRs), Electronic Patient Records (EPRs), Hospital Information Systems (HIS), Picture Archiving and Communication Systems (PACS), Radiological Information Systems (RIS) etc. There is now a very significant amount of international research which is aimed at integrating these systems into a common information environment (i.e. an advanced CIS). Web-based technology is an important component of these developments. Another important element of research in advanced CISs is the need to integrate not only medical information at the system, visceral and tissue levels, but also a wide range of Omics data (genomic, proteomic and metabolomic data). There are at least two important areas where the Swedish research groups who took part in this evaluation could immediately contribute – these are in the areas of Ontologies and advanced data mining. In more general terms there is the issue of integrating many of the post-processing methods which are being developed under image processing. Finally, Scandinavia is a world leader in mobile phone and wireless technology. This will become increasingly important in the overall context of advanced CISs. Based on their current levels of expertise, Swedish research groups should be able to work closely with Nokia and Sony-Ericsson on research in the CIS area.

Image Guided Surgery (IGS):

This is a rapidly developing field which, essentially, started in the mid 1990s with the introduction of the GE 0.5T iMR scanner. Unlike conventional scanners at that time, the iMR scanner was designed to produce 2-D images every 1.5 seconds. With the simultaneous use of an integral 3-D tracking system it was possible to track surgical instruments in near real time with an accuracy of about 0.3 mm. Since the mid 1990s there have been two key trends relating to the area of IGS. One of these is that minimal access surgery has become more and more prevalent (e.g. heart valve replacement and coronary bypass surgery can now be performed minimally invasively), and the other is that all of the major manufacturers are now selling "open" MR scanners. For example, Siemens has recently introduced a 1.0T open scanner. The panel believes that a considerable amount of the fundamental research being carried out in Sweden on medical imaging could form the basis of significant new developments in IGS. For example, the fibre tracking work using tensor analysis that is ongoing in Linköping could have application in neurosurgery, as well as the combination of MR and head-up displays.

Molecular Imaging:

In this report we have made extensive reference to research on medical imaging techniques that is ongoing within Sweden. This work has largely, but not exclusively, focused on MR, CT, US etc, i.e. techniques that are currently applied clinically at the system, visceral and tissue levels of the human organism. However, with the revolution that is occurring in molecular biology, systems biology, etc, there is a growing need to develop new and better imaging techniques which work at the cell, protein and gene levels. Imaging methods at these levels do currently exist (e.g. atomic force microscopy, cryo TEM electron microscopy and two-photon life-time techniques), while extensive research is going on concerning the imaging of molecular processes in vivo by means of ultrasound and MRI. Starting from the base of the existing research in medical imaging, it should be entirely feasible for Swedish researchers to make a major contribution in these developing areas, both by improving on existing modalities and by developing new methods.

Systems Biology:

The emerging area of systems biology, i.e. an understanding of biology as a system integrating from the molecular level to the cell and on up to tissue and organ function has the potential to revolutionize the practice of medicine. As part of systems biology, more attention should be paid to integrative modelling. This type of modelling has to include such aspects as metabolism, tissue perfusion and long term cell-cell communication and signalling pathways. This will lead to an understanding of human physiology and disease processes, and it will allow for the identification of individuals at risk and to the detection of disease at a pre-clinical stage. Engineers are educated to deal with systems, and for those engineers who have been able to integrate biology with their engineering as is the case in the cardiac research program in Linköping, a major contribution to systems biology can be made. The panel realizes that there already is some engineering activity of this type in Sweden. What may not be recognized is that, as it is applicable to medicine, it then is part of biomedical engineering. As such, it is an important area for future biomedical engineering research.

Tissue Engineering and Regenerative Medicine:

This area represents the future for the medical implant industry. Although the biomedical engineering research effort related to this area is small in Sweden, it is of high quality and thus represents a foundation for the future.

The field of stem cell biology, from the basic science to therapeutic clinical applications, is still young, but it shows every sign of becoming a pillar of tissue engineering/regenerative medicine. It is logical therefore that stem cell research will become an important component of biomedical engineering. Some biomedical engineering expertise in the stem cell area resides within Sweden (especially Chalmers). Stem cell research on the whole in Sweden benefits from the relatively liberal guidelines for human embryonic stem cell research compared to other countries. Cross disciplinary collaborative research activities with stem cell scientists will be important for the integration of current findings into the biomedical engineering field.

PANEL'S RECOMMENDATIONS FOR A JOINT CALL FOR PROPOSALS

January 27, 2006

Recommendation from the International Panel on Biomedical Engineering Research

It is the understanding of the International Panel on Biomedical Engineering Research that three funding bodies (VR, VINNOVA, SSF) will issue a joint call for research proposals within the next 3-6 months. This provides a unique opportunity to begin to implement the recommendations from the report that we are finalizing. We thus recommend the following.

1. The call for proposals should request proposals for biomedical engineering research projects that represent high risk research and that leverage Swedish strengths in clinical medicine and/or the life sciences. High risk here refers to research which will be ground breaking and, if the project is successful, will place the Swedish research community in a strong international position.
2. The three funding bodies should make available a total of 16 million Swedish Kr per year for five years to support the projects funded.
3. The funding should be divided evenly between group grants and young faculty grants.
4. The group high risk grants should involve 2-4 laboratories representing different institutions and, normally, different disciplines; these should be five year grants funded at 4 million Swedish Kr per year. The intention is that these projects should build upon existing expertise and facilities. For projects funded there should be an initial one year review and then a third year review to determine if the project is to go the full five years or be phased out.
5. The young faculty high risk grants should be funded at 1.6-2 million Swedish Kr per year for five years; these are to be prestigious awards that will allow a junior faculty member (in principle within five years of completing their postdoc) to establish an independent research program in biomedical engineering.
6. The research areas to be considered for funding are those identified as priorities by this international panel; these are in alphabetical order: biomaterials, clinical information systems, image-guided interventions, implanted sensors and integrated diagnostics, molecular imaging, systems biology, and tissue engineering and regenerative medicine.
7. The evaluation of proposals received should be conducted by an international panel.

APPENDIX 1: BME HEARINGS SCHEDULE, 16-19 JANUARY, 2006

BME Evaluation & Hearings Schedule
Stockholm, Sweden, 16-19 January, 2006

Monday 16 January, 09:00-11:30
A Medical Physics etc 1 (incl. optics)

Chair: Stephen Badylak
Anders Brahme + Bengt Lind[a], KI
Mats Danielsson, KTH
Hans Hertz, KTH
Camilla Rönnqvist, UU
Stefan Andersson-Engels + Sune Svanberg[ab], LU
Göran Salerud, LiU
Tomas Strömberg, LiU

Monday 16 January, 12:30-14:30
B Biosensing, microsystems 1

Chair: Azam Niroomand-Rad
Elisabeth Csöregi + Szilveszter Gaspar[a], LU
Bengt Danielsson, LU
Bengt Kasemo, CTH
Jan Kehr, KI
Daniel Filippini[c] , LiU (representing Ingemar Lundström's group)

Monday 16 January, 15:30-18:00
C Biomaterials, tissue engineering 1

Chair: Richard Kitney
Ann-Christine Albertsson, KTH
Tomas Albrektsson, GU
Per Aspenberg, LiU
Johan Kärrholm, GU

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[a] Accompanied submitting Group Leader in hearing
[b] Originally invited to submit report, de facto part of report submitted by other Group Leader
[c] Participated in hearing on behalf of invited Group Leader

Lars Lidgren, LU
Bo Nilsson, UU
Håkan Nygren, GU
Peter Thomsen + Rickard Brånemark[a], GU

Tuesday 17 January, 12:30-14:30
B Medical physics etc 2

Chair: Jon Cooper
Gudrun Alm Carlsson + Sören Mattsson[a], LiU
Peter Lundberg, LiU
Örjan Smedby, LiU
Mikael Persson, CTH
Freddy Ståhlberg, LU (Ståhlberg &Wirestam)

Tuesday 17 January, 15:30-18:30
C Image Processing and Information Technology, Informatics, Mathematics for BME

Chair: Stephen Badylak
Dzevad Belkic + Karen Belkic[a], KI
Ewert Bengtsson, UU
Tomas Gustavsson, CTH
Hans Knutsson, LiU
Håkan Lanshammar, UU
Anders Lansner, KTH
Helge Malmgren, GU
Per Roland, KI (invited, not attending)
Peter Wingren,UmU
Hans Åhlfeldt, LiU

Wednesday 18 January, 09:00-10:30
A Biomaterials, tissue engineering 2

Chair: Robert Reneman
Paul Gatenholm, CTH
Bo Risberg, GU
Julie Gold[b], CTH
Jöns Hilborn, UU

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[a] Accompanied submitting Group Leader in hearing
[b] Originally invited to submit report, de facto part of report submitted by other Group Leader
[c] Participated in hearing on behalf of invited Group Leader

Wednesday 18 January, 12:30-14:30
B Physiological measurement technology

Chair: Jon Cooper
Per Ask, LiU
Eva Nylander + Jan Engvall, LiU (representing deceased Bengt Wranne's group)
Matts Karlsson, LiU
Håkan Elmqvist + Lars-Åke Brodin[a], KI
Laszlo Fuchs, LU
Tomas Jansson[c], LU (representing Kjell Lindström's[b] group)

Wednesday 18 January, 15:30-17:30
C Biosensing, microsystems 2

Chair: Azam Niroomand-Rad
Maria Lindén[c], MdH (representing Ylva Bäcklund's group)
Olle Inganäs, LiU
Thomas Laurell, LU
Mamoun Muhammed, KTH + Börje Bjelke[a], KI
Göran Stemme, KTH
Peter Norlin, Acreo (Vieider & Norlin)

Thursday 19 January, 09:00-11:30
A Biomedical instrumentation and Signal processing

Chair: Robert Nerem
Stig Arlinger, LiU
Bo Håkansson, CTH
Arne Leijon, KTH
Zoran Popovich[c], GU (representing Jan Olof Karlsson's group)
Kaj Lindecrantz, HB (earlier at CTH)
Leif Sörnmo, LU
Karin Wårdell, LiU

Thursday 19 January, 13:00-14:30
B Groups associated to the Artificial hand project, etc

Chair: Robert Reneman
Nils Danielsen, LU
Martin Kanje, LU
Göran Lundborg, LU

Regrets: Eriksson, Lars (lives in the US now)

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[a] Accompanied submitting Group Leader in hearing
[b] Originally invited to submit report, de facto part of report submitted by other Group Leader
[c] Participated in hearing on behalf of invited Group Leader

APPENDIX 2: LIST OF EVALUATED GROUPS AND GROUP LEADERS

Group Leader [1]	Univ etc	Group Name	Includes other originally invited Grant Holders [2]	BME Main Areas [3]	URL address
Albertsson Ann-Christine	KTH	Biomedical Functional Polymers		15, 1	www.polymer.kth.se
Albrektsson Tomas	GU	Biomaterials/handicap research	Wennerberg Ann	15, 2, 1, 3	www.sahlgrenska.gu.se/biomaterials/
Alm Carlsson Gudrun	LiU	COMEX	Sandborg Michael	10, 8, 2	http://huweb.hu.liu.se/inst/imv/radiofysik/
Andersson-Engels	SLU	Medical Laser Physics	Svanberg Sune	4, 8, 7, 13	www.atom.fysik.lth.se
Arlinger Stig	LiU	Technical Audiology		12	http://infoweb.unit.liu.se/hu/inr/ta/
Ask Per	LiU	Physiological Measurements	Öberg Åke	7, 14, 4	www.imt.liu.se
Aspenberg Per	LiU	Experimental Orthopedics in Linköping		1	www.hu.liu.se/inr
Belkic Dzevad	KI	Magnetic Resonance Spectroscopy and Imaging group at KI		8, 10, 15	http://onkpat.ki.se/forskning/belkic
Bengtsson Ewert	UU	Centre for Image Analysis		8	www.cb.uu.se/
Brahme Anders[4]	KI	Radiation Therapy of Excellence		10	http://radfys.ki.se
Bäcklund Ylva	MdH	Biomedical Engineering		8, 7, 9	www.mdh.se
Csöregi Elisabeth	LU	Biosensors		5, 11	www.analykem.lu.se/biosens/mainpage. html
Danielsen Nils	LU	Unit of Neural Interfaces	Montelius Lars	1, 5, 11	www.lu.se/

Group Leader [1]	Univ etc	Group Name	Includes other originally invited Grant Holders [2]	BME Main Areas [3]	URL address
Danielsson Bengt	LU	Bioanalysis		5	www.tbiokem.lth.se
Danielsson Mats	KTH	KTH High resolution X-ray Imaging Group		2	www.particle.kth.se
Elmqvist Håkan	KI	Avd f medicinsk teknik	Bone Dianna, Ollmar Stig	6, 7	www.ki.se
Eriksson Lars	KI	Design of positron camera systems optimized for animal studies and oncology		2	www.cns.ki.se/
Fuchs Laszlo	LU	Fluid Mechanics		3	www.fm.vok.lth.se
Gatenholm Paul	CTH	Biopolymer Technology		1	www.pol.chalmers.se
Gustavsson Tomas	CTH	Imaging and Image Analysis		8	www.s2.chalmers.se
Hertz Hans	KTH	Biomedical & X-Ray Physics		2, 5	www.biox.kth.se
Hilborn Jöns	UU	Polymer Chemistry		1	www.polymer.uu.se
Håkansson Bo	CTH	Hearing Research Group		12, 7	www.s2.chalmers.se
Inganäs Olle	LiU	Biomolecular and organic electronics		5	www.ifm.liu.se/biorgel
Kanje Martin	LU	Zoological Cell Biology/ Nerve Regeneration		5, 11, 1	www.darwin.biol.lu.se/cellorgbiol/nerveregen/index.html
Karlsson Jan-Olof	GU	Adaptive optics group		2	www.anatcell.gu.se/
Karlsson Matts	LiU	Biomedical Modelling and Simulation		3, 6, 2	www.imt.liu.se/bms
Kasemo Bengt	CTH	Chemical Physics	Gold Julie	1, 5, 7, 15	www.fy.chalmers.se/kemfys/

Group Leader [1]	Univ etc	Group Name	Includes other originally invited Grant Holders [2]	BME Main Areas [3]	URL address
Kehr Jan	KI	Section of Pharmacological Neurochemistry		11	www.fyfa.ki.se/elements/research/leaders.html
Klintström Stefan (Repr.)	LiU	Forum Scientium		15	www.liu.se/scientium
Knutsson Hans	LiU	Medical Informatics (Image Science)	Borga Magnus	8, 15	www.imt.liu.se/mi/
Kärrholm Johan	GU	Joint Replacement and Radiostereometry Unit		15	www.jru.orthop.gu.se
Lanshammar Håkan	UU	Biomechanics		3	www.it.uu.se/research/syscon/biomech
Lansner Anders	KTH	SANS	Grillner Sten	11, 3, 7	www.nada.kth.se/sans
Laurell Thomas	LU	Electrical Measurements	Lindström Kjell, Nilsson Johan, Persson Hans W	5, 14, 11, 6, 13, 2	www.elmat.lth.se
Leijon Arne	KTH	Hearing Technology		12	www.s3.kth.se/sip/
Lidgren Lars	LU	Dept of Orthopedics, Clinical sciences		1	www.ort.lu.se
Lindecrantz Kaj	HB/ CTH	Biomedical Engineering Group		8, 7, 9	www.ing.hb.se/research/medical-en.php
Lundberg Peter	LiU	MR-unit		10	huweb.hu.liu.se/inst/imv/radiofysik/en/
Lundborg Göran	LU	Department of Hand Surgery		11	www.hand.mas.lu.se
Lundström Ingemar	LiU	Division of Applied Physics		5	www.ifm.liu.se/~ingemar/
Malmgren Helge	GU	ANNIMAB		8	www.phil.gu.se/annprojeng.html
Muhammed Mamoun	KTH	Materials Chemistry		1	www.kth.se

Group Leader [1]	Univ etc	Group Name	Includes other originally invited Grant Holders [2]	BME Main Areas [3]	URL address
Nilsson Bo	UU	Clinical Immunology (Biotechnology)	Larsson Rolf	1, 13	www.uu.se
Nygren Håkan	GU	Anatomi och cellbiologi		2	www.anatcell.gu.se
Persson Mikael	CTH	Elektromagnetic Bio and Plasma Physics Group		2, 15	www.elmagn.chalmers.se /MPgroup
Risberg Bo	GU	Vascular Engineering Centre		1	www. wlab.gu.se
Roland Per	KI	Brain Research		11	www.neurogenerator.org
Rönnqvist Camilla	UU	DIgital X-ray Imaging (DIXI) in Graduate School Advanced Instrumentation and Measurements (AIM)		8	www.aim.uu.se
Salerud Göran	LiU	Biomedical Instrumentation		4, 2	www.imt.liu.se
Smedby Örjan	LiU	Medical Radiology / CMIV		8, 6, 11	www.cmiv.liu.se
Stemme Göran	KTH	Microsystem Technology		5, 6, 13	www.s3.kth.se/mst/
Strömberg Tomas	LiU	Div Biomedical Instrumentation/Group Circulation and Respiration Physiology Measurement Methods		4, 7	www.imt.liu.se/bit/
Ståhlberg Freddy	LU	MR Physics Group	Wirestam Ronnie	10, 8	www.jubileum.lu.se/ MR_physics
Sörnmo Leif	LU	Signal processing group		8	www.es.lth.se
Thomsen Peter	GU	Cell Biology Group, Department of Biomaterials		15	www.sahlgrenska.gu.se www.biomaterials.gu.se

Group Leader [1]	Univ etc	Group Name	Includes other originally invited Grant Holders [2]	BME Main Areas [3]	URL address
Vieider Christian	Acreo	Sensors group	Norlin Peter	5	www.acreo.se
Wingren Peter	UmU	Projective properties of fractal sets		8	http://abel.math.umu.se /analysis/fraktaler/ index. html
Nylander Eva (after deceased Bengt Wranne)	LiU	Department of Medicine and Care/Clinical Physiology		6, 14, 2	www.cmiv.liu.se
Wårdell Karin	LiU	Biomedical Instrumentation - Minimally Invasive Instrumentation		11, 4, 7, 13, 8	www.imt.liu.se/bit/mint/
Åhlfeldt Hans	LiU	Medical Informatics	Karlsson Daniel	9	www.imt.liu.se

[1] Grant Holder who submitted a background report. See Evaluation Process for further details.

[2] Some of the Grant Holders that were asked to submit background reports chose to use the option to report jointly with another Grant Holder, with the latter as the "official" submitter of the joint report, called Group Leader. See Evaluation Process for further details.

[3] See Evaluation Process for description of BME main areas.

[4] Other recent evaluation material was used.

APPENDIX 3: EXECUTIVE SUMMARIES OF BME BACKGROUND REPORTS

Executive Summaries of group's scientific profile and major research directions pursued during the period of evaluation

Division or Group Leader[1]:	Ann-Christine Albertsson
Name of Division or Group:	Biomedical Functional Polymers
University:	KTH

Executive Summary

Our aim is to synthesize resorbable polymers and networks with specific, functionalized architecture and to develop artificial implants by cell and tissue engineering, targeting on soft tissues and devices for controlled drug release. Our work is divided into four main parts:

- Polymer synthesis including the functionalization of the polymers, copolymerization, creation of networks, and preparation of porous scaffolds.
- Design and development of biomedically adapted surfaces, with special attention to the development of modification techniques such as grafting or nano-patterning.
- Characterization of the materials and the effect of different parameters on the degradation process.
- Applications in the field of tissue engineering.

We bring together the design of new functional biomaterials, design and development of biomedically adapted surfaces, advanced characterization, evaluation of degradation and degradation products, biocompatibility testing and finally relevant industrial partners with expertise in the development and production of biomedical products. The most valuable contribution of the program is the establishment of this cooperation that brings together all the necessary pieces in the jigsaw puzzle, making it possible to design and develop the next generation of biomaterials with the right degradation time and the correct degradation products, right surface properties and good biocompatibility, and to turn these materials into commercial products.

Division or Group Leader[1]: Tomas Albrektsson
Group also includes Grant Holder[2]: Ann Wennerberg
Name of Division or Group: Biomaterials/Handicap Research
University: GU

Executive summary

The senior scientist of this report, Albrektsson, participated in the team that developed the very first internationally acceptable oral implants. It was demonstrated that reliable clinical results were achieved through osseointegration, direct bone anchorage, of titanium screws. Our research has been centered on two main areas: Basic science to understand the background to osseointegration and widen clinical applications to other areas. Our group has worked with comparisons between titanium and other materials, investigated various implant designs, developed new approaches for surface topographical analyses and developed new potentially bioactive implants. Clinical factors such as host bone response to irradiation, electrical stimulation and supplementation of growth factors have been studied, as well as the importance of surgical and prosthodontic routines. Routines for clinical reporting have been lined out and published, Albrektsson was a co-worker and co-author of the very first publications on a new application of osseointegration, that of bone anchored and skin penetrating craniofacial implants used for certain types of hearing disorders (then coupled to a hearing aid) and to treat congenital malformations (then coupled to facial epistheses). Albrektsson was the senior member of the team that developed new arthroplasties and tested those experimentally, started up randomised clinical trials of those and are now exploting them for more widespread clinical usage.

Division or Group Leader[1]: Gudrun Alm Carlsson
Group also includes Grant Holder[2]: Michael Sandborg
Name of Division or Group: COMEX
University: LiU

Executive summary

The goal of our research is to develop scientifically based methods for characterising and optimising digital medical x-ray imaging systems. To this end we have (1) developed methods to measure the physical characteristics

1 Grant Holder who submitted a background report. See Evaluation Process for further details.
2 Some of the Grant Holders that were asked to submit background reports chose to use the option to report jointly with another Grant Holder, with the latter as the "official" submitter of the joint report, called Grop Leader. See Evaluation Process for further details.

(MTF, Noise power spectrum, DQE, NEQ) of image receptors; (2) developed a computational model of the x-ray imaging system that simulates the transport of x-rays form the x-ray source to the image receptor. The model includes an anthropomorphic voxel phantom to simulate the patient and allows that physical image quality parameters (contrast and signal-to-noise ratio and patient dose are calculated simultaneously; (3) developed quality criteria and methods to quantify clinical image quality using descriptors based on features of normal anatomy; (4) developed hybrid images (patient images with added pathological lesions) in order to use detect ability of anatomical lesions as an additional image quality criterion (5) applied ROC (receiver operating characteristics) to evaluate the detect ability of lesions in the hybrid images; (6) arranged clinical trials with expert radiologists for the evaluation of clinical image quality according to the selected criteria; (7) tested various task dependent physical image quality descriptors that can be positively linked to the clinical image quality descriptors.

Division or Group Leader[1]:	Stefan Andersson-Engels
Group also includes Grant Holder[2]:	Sune Svanberg
Name of Division or Group:	Medical Laser Physics
University:	LU

Executive summary

The research is within the field of biomedical optics with clinical applications. We have been working with methods to measure optical properties, both for diagnostic purposes and for dosimetry in connection to photodynamic therapy. The gained expertise in modelling and measurements of optical properties has been used to develop a novel interstitial photodynamic system with on-line feedback. Spectroscopy is here used to reveal presence of important constituents for PDT during the treatment: light, photosensitizer and oxygen. For these measurements we have also employed the long experience of fluorescence spectroscopy for tissue diagnostics, in itself another main area of research, with several clinical evaluation studies with positive results. Much effort has been paid to develop tools for time-resolved diffuse remittance spectroscopy to measure absorption and scattering spectra. Developed instruments and evaluation routines have been used in optical mammography research and have also gained interest for in-line control measurement in the pharmaceutical industry. The development of a novel technique to measure absorption of a gas in highly scattering materials has been successful. A novel technique for sinus cavity monitoring was introduced. We have also developed novel laser-based X-ray sources for radiographic imaging, where the small source size and possibilities for gated imaging suppressing scattered X-rays, provide interesting prospects in reduced absorbed dose.

Division or Group Leader[1]: Stig Arlinger
Name of Division or Group: Technical Audiology
University: LiU

Executive summary

Our group was an active partner in the development of the first hearing aid with full digital signal processing in the world, in cooperation with our industrial partner Oticon in Denmark. This work and the subsequent work on the relation between technology and behavioural sciences, especially cognition, have been landmarks where the group has made significant impact. We have been partner in a recently finished EU-project concerning rechargeable batteries for hearing aids and cochlear implants, and are partner in another large EU-project "Hearing in the communication society" which started 2004. Our work on noise, noise-induced hearing loss and hearing protectors is another area where we have been unique in Sweden and also in an international perspective. Our present research continues to focus on the interaction between advanced signal processing in digital hearing aids and human factors such as type and degree of hearing loss, cognitive functions, and sound awareness.

Division or Group Leader[1]: Per Ask
Group also includes Grant Holder[2]: Åke Öberg
Name of Division or Group: Physiological Measurements
University: LiU

Executive summary

A research profile is model driven flow estimation using ultrasound and bioacoustic techniques, mainly with cardiovascular applications. This includes simulation and signal processing of the ultrasound and bioacoustic signal to optimize parameters that can be related to the physiological information.

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We are working on optimizing tissue blood perfusion measurements using ultrasound contrast. An interesting fact is that these bubbles can be made targeted and include therapeutic substances. The bioacoustic research which include advanced signal processing has a goal to build the intelligent stethoscope as a tool in home health care. Our biooptical research has a focus on photopletysmography and optical spectroscopy with the intention to study blood flow parameter and tissue constituents. We take advantage of having knowledge about different measurement modalities by working out new strategies for wearable multisensor design for distributed health care. These sensors will be part of a system with large information technology content. We have the aim to continue to be one of the leading groups in physiological measurements in Europe. Per Ask was with professors Bengt Wranne (cardiology) and Dan Loyd (fluid dynamics) in 1983 cofounders of the Cardiovascular Dynamics Research Group. This group has reached international recognition and its research has proliferated. Today the group consists of a faculty of about 15 biomedical engineering and medical researchers at different departments and divisions and has extensive international research cooperation. The division is deeply involved in the VINNOVA funded NIMED center of excellence for research cooperation with industry. We are part of the SSF funded Cortech network of excellence for cardiovascular engineering research.

Division or Group Leader[1]:	Per Aspenberg
Name of Division or Group:	Experimental Orthopedics in Linköping
University:	LiU

Executive summary

We develop and use animal models for studies on the biology that follows upon surgical interventions in the musculoskeletal system. This involves the anchoring and spontaneous loosening of bone implants, various bone replacement materials, and bone and tendon repair. Especially, we use common or unique drugs, mostly locally applied, to influence these processes. New theories for the cause of prosthesis loosening have been formulated and tested. Metal implants coated with bioactive substances are developed and show improved function. Fracture and tendon repair has been accelerated by systemic and local pharmacological treatment. The influence of mechanical loading is also involved in these studies. After many years of mostly experimental work, we now also have an increasing number of clinical studies running.

Division or Group Leader[1]:	Dzevad Belkic
Name of Division or Group:	Magnetic Resonance Spectroscopy and Imaging Group
University:	KI

Executive summary

Major research directions: 1) Advanced processing of time signals from magnetic resonance spectroscopy (MRS) 2) Medical radiation physics Transport of Charged Particles through Tissue 3) Work Environmental & other Psychosocial Risk Determinants Area #1 is our primary activity. The expertise of the Grant Holder, a theoretical atomic physicist has been the pivotal impetus for this research direction, begun by the novel application of quantum mechanical methods to signal processing. Time signals have been encoded in many experiments in physics & chemistry by using various measuring techniques such as Ion Cyclotron Resonance (ICR) Mass Spectroscopy, Infrared Spectroscopy, NMR, etc. The fast Pade transform (FPT) has been successfully applied to a wide array of such signals. MRS is, in fact, in vivo NMR. Signals from MRS are of precisely the same type as those encoded by NMR or ICR in chemistry. Therefore, it is expected that the methods established in NMR or ICR physics/chemistry are of direct relevance to MRS. This has been demonstrated recently in our publications by using the FPT applied to in vivo time signals encoded via MRS. The expertise of the other group leader, a physician researcher has linked this research directly to clinical oncology. Area #2 is also pursued by the Grant Holder, while Area #3 is pursued by the other project leader, clinician researcher.

Division or Group Leader[1]:	Ewert Bengtsson
Name of Division or Group:	Centre for Image Analysis
University:	UU

Executive summary

The Centre for Image Analysis is a collaboration between Uppsala University and the Swedish University of Agricultural Sciences. The Centre was established "to develop and reinforce the knowledge needed for an operative and sensible use of digital image analysis in society, particularly in the fields of environmental and medical science". To fulfil this we conduct fundamental

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research in image analysis, particularly relating to discrete geometry and 3D shape analysis, and carry out applied image analysis projects in cooperation with medical and biological researchers. Our main biomedical application focus has been on cell image analysis and on 3D image analysis from tomography. For cell images there has been a shift from transmission light microscopy to fluorescence microscopy. In addition to automatic segmentation and analysis methods we are also developing interactive approaches including visualisation. This has recently been supplemented by haptic interaction.

Division or Group Leader[1]:	Anders Brahme
Name of Division or Group:	Radiation Therapy Centre of Excellence
University:	KI

Executive summary

The main activities at the department of Medical Radiation Physics and the Research Center for Radiation Therapy, supported by VINNOVA, are focused on the development of improved methods and devices for diagnostic and therapeutic radiology. Traditionally the focus has been on the development of improved radiation therapy methods such as Intensity Modulated Radiation Therapy (IMRT), Light Ion Therapy (LIT) and most recently, radiation Quality Modulated Radiation Therapy (QMRT). We have initiated a world leading development of biologically optimized therapy where radiobiological models for different tissues and tumors are used to maximize the complication free cure for cancer patients with a severe disease using IMRT, LIT and QMRT. To bring some of our most important innovations faster to clinical practice we have initiated a handful of companies in the medical Physics and Engineering arena. The most important products include software for Biologically Optimized Treatment Planning, a 4D-Laser camera for accurate patient set up (0,1 mm) and Image Fusion, a fast Detector for radiation beams based on gas electron multipliers, new dedicated Treatment Units for fast efficient IMRT, Diagnostic treatment units combining PET-CT and radiation therapy, and most recently a lightweight cost effective Gantry for LIT. Key activities at the department are also to develop mathematical procedures to increase the efficiency of medical care and research. In the BIOCARE-project (6th FP of EU) we are today coordinating the development of new methods for Molecular Tumor Imaging where we can image by PET-CT, the 3D dose delivery, during high energy photon and light ion therapy, the radiation responsiveness of the tumor and the effects of tumor hypoxia on the therapeutic efficiency. To increase the understanding of tumor development and treatment, new functional genomic methods are also currently being developed to better select the optimal treatment approach based on micro array data.

Division or Group Leader[1]: Ylva Bäcklund
Name of Division or Group: Biomedical Engineering
University: MdH

Executive summary

Our research group is young, dynamic and expansive. Before 1999 none of the senior researchers were working at Mälardalen University. We have now grown into a matured and productive research group, known both nationally and internationally. We have concentrated on wireless, wearable sensor systems for supervision of physiological data. So far, Bluetooth has been used as a communication standard but the same principle can be used in other standards as w-lan, RFID and Zigbee. Also, multisensor systems facilitate a more holistic view over the health status, not measuring a single parameter at a time. For example, we have systems combining ECG with the heart sound and blood flow (PPG) (collaboration with the Linköping group). Further, sensor systems with integrated intelligence are more appropriate in several situations. E.g. a system used in stress medicine measures heart rate, breathing rate, carbon dioxide level, oxygen saturation and skin conductivity, interprets the data and provides a feedback to the "patient". Decision support systems and knowledge discovery enables this. Through build-in intelligence, sensor information can be better utilised. In telemedicine applications, only a limited amount of data will have to be transmitted, saving energy, which is important if battery situations. Another area is the newly started field within microwaves for medical imaging as well as a novel way to measure CO_2 in expired air through a resonant sensor. These fields/contributions, are fairly new but very promising, and with a great potential and a good chance for Swedish industry to become competitive.

Division or Group Leader[1]: Elisabeth Csöregi
Name of Division or Group: Biosensors
University: LU

Executive summary

Our group is developing analytical tools obtained by the combination of electrodes with biological recognition. Research interest includes electrode design, immobilization of biomolecules, design and engineering of electron

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transfer pathways between enzymes and electrode, and interference elimination. The developed biosensors can be used in environment monitoring (e.g. detection of heavy metals in contaminated soils), in food and beverage industry (e.g. monitoring of biogenic amines in fish) and in the biomedical field. Major interest in this field is focused on monitoring neurotransmitters using three approaches to reveal the biochemical background of different brain disorders and to follow the effect of different treatments:1) arrays of biosensors positioned inside the wells of cell culture plates, for simultaneous monitoring of NO and glutamate released from cells, 2) flow-through microdetectors, for simultaneous detection of glucose, choline, and glutamate, in combination with microdialysis sampling, and 3) needle type micro-biosensors, to detect glutamate or catecholamines in vivo. An important aspect of our research is integration of the developed biosensors with other techniques in order to record complementary information; electrochemical monitoring of neurotransmitter release was combined with fluorescent monitoring of intracellular species, and needle-type biosensors were integrated into SECM for detection at cell culture level as well.

Division or Group Leader[1]: Nils Danielsen
Group also includes Grant Holder[2]: Lars Montelius
Name of Division or Group: Unit of Neural Interfaces
University: LU

Executive summary

The Artificial Hand Project consists of a network of scientists sharing the same vision, ie to create an artificial hand that is controlled by nerve signals. In order to fulfil this vision a number of competences and disciplines need to be involved and a cross-disciplinary approach to the problem is essential. The network consists of scientific groups with a background in neurophysiology, hand surgery, neurobiology, electrical measurements, silicon processing, nanoscience and cognitive science. So far we been able to register nerve signals from silicon based electrodes implanted in peripheral nerves. With the use of artificial neural network and EMG recordings we have demonstrated that hand amputated patients can control a virtual hand in real time. We have also described the tissue reactions evoked by implanted silicon. During these years this network has evolved from aiming at a specific project to a constellation of senior and junior researchers with a broader and more general approach to the Brain Machine Interface field. Our competence about other disciplines within the network and also the way we interact have evolved. We are now in the process of forming a Neuronanoresearch Center. The rapid advancement of nanoscience and its future application in biomedical science is one of the driving forces behind this process. The envisioned Neuronanoresearch Center will focus on implantation of nanostructured multichannel electrodes into the CNS with the purpose of controlling various prosthetic devices.

Division or Group Leader[1]:	Bengt Danielsson
Name of Division or Group:	Bioanalysis
University:	LU

Executive summary

We are continuing development of thermal biosensors for use in biomedical analysis, process control and monitoring, environmental control, metabolite monitoring, miniaturized sensors, and thermal chips. This is an original and world-leading concept developed at our department. Current studies involve development of portable multichannel devices in combination with mobile data handling for decentralised medicine. Optical systems for binding assays of e.g. pesticides in different formats for HTS using CCD cameras and for single samples using PMTs. Fluorescent monitoring of compounds interacting with nucleic acids. Nanotechnological studies of biological systems and interactions using AFM and SNOM. Studies of affinity arrays of lectins and antibodies using SPR and ellipsometry for bacterial and medical diagnoses.

Division or Group Leader[1]:	Mats Danielsson
Name of Division or Group:	High resolution X-ray Imaging Group
University:	KTH

Executive summary

Our ultimate long term goal is to revolutionize medical x-ray imaging. We believe that this will, depending on the application, involve detectors that are faster, more efficient, higher contrast and spatial resolution. We also believe that combining the new detectors with novel x-ray optics will be important. We use computer simulations to evaluate the new concepts for systems typically consisting of Applications Specific Circuits, detectors and x-ray optics and this is done in parallel with performing numerous experiments. One outcome will be

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that the radiation dose to the patient can be dramatically reduced for some examinations where this is essential. The first photon-counting detector system in clinical praxis is one result of the research performed within the group and this currently constitutes the only European technology platform for digital mammography, currently marketed by the Swedish company Sectra and with numerous installations worldwide. Also the saw-tooth and multi-prism x-ray focusing devises where invented in the group, the first published in Nature. In collaboration with Karolinska Hospital also a new portal imaging detector for optimisation of radiation therapy has been developed. Our current research projects more specifically focus on 1) X-ray optics for scanning imaging systems 2) Evaluation of a new concept for child CT enabling a major dose reduction 2) Imaging of contrast agents including bio.labeled nano-particles using photon counting detectors. The last years we have seen an increasing interest from leading scientists from abroad (Japan, USA) to join the group as guest researchers, typical stay is half a year and fully supported by institutions in the respective home countries. The group typically consists of two senior researchers, one guest researcher and four Ph.D. students.

Division or Group Leader[1]:	Håkan Elmqvist
Group also includes Grant Holder[2]:	Dianna Bone and Stig Ollmar
Name of Division or Group:	Section of Medical Engineering
University:	KI

Executive summary

During the period the group has focused on new technical methods in cardiovascular disease within several areas: Gamma camera imaging; Echocardiography; Monitoring of cardiac work; optimal pacing; Improving diagnostic accuracy of stress EKG and Computer simulation of cardiac electrophysiology. Beside these areas we have addressed Breathing and respiratory drive in man; Skin impedance as a diagnostic tool and Medical devices in Sweden industrial structure, production and foreign trade 1985-2002. The recently completed Cortech programme, supported by the Foundation for Strategic research, has been very important for our development. Cortech is a collaboration between the departments for medical engineering at the universities of Lund and Linköping and the Karolinska Institute. Cortech had two objectives 1) research on technical methods in cardiology 2) improvement of postgraduate training in medical engineering. So far Cortech has resulted in 11 dissertations, 8 licentiate examinations, 21 PhD courses and 43 published papers. Besides these tangible results an effect of Cortech is a much improved collaboration between the involved institutions and people.

Division or Group Leader[1]:	Lars Eriksson
Name of Division or Group:	Design of positron camera systems optimized for animal studies and oncology
University:	KI

Executive summary

The main focus has been to design high resolution PET systems. In the first stage we focused on systems for animal studies. In a second stage the focus was more on design of whole body scanners for oncology in humans. Regarding the design of animal PET systems, we looked at different possible solutions. The most promising alternatives were based on detector panels following design criteria developed in collaboration with CTI for a high resolution research tomography (HRRT), now delivered to around 15 research centres for brain research. One system was based on six HRRT detector panels arranged in a hexagon while the other solution used two HRRT detector panels rotating around the imaged animal. In both cases a spatial resolution between 1-2 mm was expected. We tried to get funding for these two alternatives, in 1998 from both TFR and the Wallenberg foundation for the first alternative, and in 2000 from TFR for the second alternative, however, with negative outcome for the two applications. We have more recently looked at the panel concept for oncology studies in humans with large axial extensions, up to 53 cm. A prototype with five rotating detector panels has been built by CTI and is now installed in our partner, Professor David Townsend's department at the University of Tennessee, Knoxville. Most of the human torso can be scanned with only two bed motions with a 4-5 mm spatial resolution and with the highest sensitivity ever reported.

Division or Group Leader[1]:	Laszlo Fuchs
Name of Division or Group:	Fluid Mechanics
University:	LU

Executive summary

1. We have shown that differential diffusion is important for intermittently turbulent flows (both flows in arteries and upper parts of the respiratory tract). This effect leads to non-homogenous mixture of blood cells and

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different solvents (small vs. macro-molecules). Important impact on atherosclerosis and drug administration through inhalation. This effect has not been reported previously in connection to biological flows. 2. The mechanism of arterial aneurism and its dependence on flow instability and wall shear-stress variation (in the process of publishing).

Division or Group Leader[1]:	Paul Gatenholm
Name of Division or Group:	Biopolymer Technology
University:	CTH

Executive summary

The research program initiated by Professor Paul Gatenholm in year 2000 aims to develop technology required for the transformation of selected biopolymers into advanced biomacromolecular materials. The program is focused on altering the molecular structure of polysaccharides by enzymatic and chemical means in order to control their ability to assemble into solid materials with hierarchical architecture (similar to one existing in biological materials). The surface and interfacial properties of these new biomimetic materials are of major interest. The range of potential applications of the new materials prepared in this program stretches from barrier films and coatings, novel fibres, bioadhesives, biocomposites for automotive applications to scaffolds for tissue engineering. Our research attracted interest in direct clinical applications which is reflected by two VR funded projects where we develop polysaccharide structures for applications as scaffolds for tissue engineering of blood vessels and cartilage. We are also participating in EC project Expertissue which aims to develop new biomimetic scaffolds for tissue engineering of cartilage and bone.

Division or Group Leader[1]:	Tomas Gustavsson
Name of Division or Group:	Imaging and Image Analysis
University:	CTH

Executive summary

The scientific profile of our Group is Bioimaging and image analysis. This means we try to understand the physical principles of the imaging device (e.g. ultrasound, MRI, microscopy, etc) at hand and use that as a starting point for our image analysis. We believe that any image analysis must be performed with an in-depth understanding of the imaging process (e.g. point-spread function, contrast resolution, illumination uniformity, noise characteristics, etc). As for the image analysis as such, we have to a large extent been using physics based methodologies (such as deformable modeling and related) and mathematical-statistical modeling (e.g. Hidden Markov modeling, Kalman filtering etc), i.e. a solid theoretical framework. However, because we are application-oriented rather than theory-driven, we sometimes apply ad-hoc algorithms if this is needed to solve a given problem. Our main applications have been cardiovascular- and neuro-oriented. The field of imaging and image analysis is very broad and so require a broad expertise. No way a single group of our size can host all these expertise needed. Therefore, besides collaborating with clinicians and biologists, we establish alliances with experts in physics (bioimaging) and mathematics (statistics). This makes our Group much stronger and competitive.

Division or Group Leader[1]:	Hans Hertz
Name of Division or Group:	Biomedical & X-Ray Physics
University:	KTH

Executive summary

We apply modern physical methods and technology with the long-term aim to solve problems in biology, medicine, and materials science. // One important field of research is x-ray science and technology. Here a new high-brightness liquid-jet-target laser-plasma source has been developed. By combining this source with novel x-ray optics we have recently demonstrated the first sub-visible-resolution compact x-ray microscope. Such microscopes show promise for cell-biological studies where high resolution is important. Furthermore, one another version of the liquid-jet source was developed for EUV (Extreme Ultraviolet) projection lithography systems, for future production of integrated circuits with very narrow line widths. In a new project, we demonstrate high-brightness hard x-ray generation with an liquid-metal-jet anode electron-impact source. This source shows promise to allow medical imaging with 10x higher resolution than present rotating-anode sources.// In addition to the x-ray science and technology, optical and acoustical methods for biomedical applications are investigated. Here acoustical radiation forces are used for high-sensitivity bio-analytics

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and gentle cell handling in microfluidic systems. Confocal microscopy is developed and used for measurements of intracellular parameters. Finally, the optical system of the human eye is investigated, with the aim of improving peripheral vision for people with central visual field loss.

Division or Group Leader[1]: Jöns Hilborn
Name of Division or Group: Polymer Chemistry
University: UU

Executive summary

Polymer chemistry in Uppsala started in 2001 with building of the lab, proposal writing, course developments and hiring of staff. Scientifically the research interests can be divided into polymers for drug delivery (Dr. Tim Bowed) and implants/scaffolds for tissue engineering (Hilborn). We synthesize new materials (incl. biosynthesis) that should elicit specific response in-vivo by themselves of by their combinations with bioactive molecules like growth factors. The laboratory have now capabilities to synthesize new biodegradable polymers, prepare sterile samples, test these in culture, grow cells under dynamic stimulation and produce extracellular matrix. We routinely test materials in animals through close collaborations with Professor Bjursten in Lund. Scale up of polymer synthesis up to 2 kg are done in house while processing is done through collaborations.

Division or Group Leader[1]: Bo Håkansson
Name of Division or Group: Hearing Research Group
University: CTH

Executive summary

Our research direction has been on understanding the mechanisms behind hearing by bone conduction and to find new technical solutions for improving bone conduction hearing aids and bone conduction audiometry. In particular the group has been deeply involved in the technical development of the Bone Anchored Hearing Aid (BAHA) that today is used by more than 25 000 patients and for the early contributions the researchers (Håkansson & Carlsson) won the Innovation cup 1989. Other research areas related to bone conduction hearing focused on are: bone conduction hearing testing, fitting and evaluation of BAHA, hearing systems for extremely noisy environments, hearing the own voice, amelioration of stuttering and tinnitus relief.

Division or Group Leader[1]: Olle Inganäs
Name of Division or Group: Biomolecular and organic electronics
University: LiU

Executive summary

We have developed the uses of electronic polymers as interfaces to biological systems, ranging from microactuators for cells (and microsystems), to polymer hydrogel microelectrodes for neural interfaces, and more recently, the use of electronic polymers in the form of conjugated polyelectrolytes for purposes of biodetection. Such polymers are also candidates for biochip detectors, and we have contributed towards the patterning methods for biochips printed with soft lithography.

Division or Group Leader[1]: Martin Kanje
Name of Division or Group: Zoological Cell Biology/Nerve Regeneration
University: LU

Executive summary

Our project consists of a network of scientists sharing the same vision - the development of a biocompatible, nanoelectronic chip/interface to monitor and stimulate electrical activity in the nervous system. This requires a cross-disciplinary approach. During the last few years we have managed to establish a unique constellation of senior and junior researchers within the BMI field. We have also been able to create a new type of organisation where young scientists work across the faculty boarders in close collaboration. One of our most important strategies to strengthen the cross-disciplinary work regular seminar/meetings run by Dr Cecilia Eriksson Linsmeier. Here senior and junior researchers meet to discuss work progress, results, proceedings of projects, and listen to invited speakers, both from industry and academy. Thus, we have assembled and built up a unique group for BMI research in Sweden which covers aspects from the molecular mechanism of nerve cell/chip interactions to clinical applications of cutting edge BMI constructs. Major research directions pursued include the evaluation of nanowires and porous silicon as new electrode materials and the sorting of different types of nerve fibres on the chip surfaces. These ideas are unique to our programme.

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Division or Group Leader[1]: Jan-Olof Karlsson
Name of Division or Group: Adaptive Optics Group
University: GU

Executive summary

In the next few years, the detection of retinal disease will become more dependant upon emerging automated retinal imaging techniques. Disease management is already increasingly dependant upon quantitative imaging techniques as well as direct visualisation, and automated imaging in one form or another will form a large part of the management of patients with ocular disease in the future. Morphological, functional and high-resolution images are beneficial to accurately determine and control the impact of a particular treatment protocol. Potentially, many key indicators of advanced retinopathy that are today difficult to visualise and quantify could be more effectively monitored and managed using emerging technologies, such as Adaptive Optics, Optical Coherence Tomography, Scanning Laser Ophthalmoscopy. These include: Diabetic retinopathy (macular oedema), other retinal vascular diseases, glaucoma, age-related maculopathy, choroidal new vascularization, inflammatory conditions (e.g. Cytomegalovirus retinitis), and inherited retinal degenerations. Also, in the short to medium term there will be new drugs and/or treatments like gene and stem cell therapy able to act on the precursors of sight threatening retinopathies. To facilitate the delivery and dosage control of these drugs and to monitor treatment success will require automated imaging techniques not in place today.

Division or Group Leader[1]: Matts Karlsson
Name of Division or Group: Biomedical Modelling and Simulation
University: LiU

Executive summary

Non-invasive estimation of parameters relevant for diagnosis, intervention planning and follow-up has always been the basis of the research within the research group. We focus on first principle modeling where the basic equations of motion are playing an important role. Thus, we are able to use these models for predictive simulations. The core of our work resides in the border zone between continuum mechanics, computational engineering and basal physiology. The pioneering work on 3D time-resolved phase contrast MRI combined with the SUN Fire supercomputer that was enabled by a TFR grant, formed the basis for a unique research profile that has lately been transformed into the Center for Medical Image Science and Visualization (CMIV).

Our early work in this field included both MRI method development and some new computational techniques whereas our more recent work has moved more and more into the direction of modeling and simulation. The latter enabled the establishment of the Division of biomedical modelling and simulation where we have concentrated on a number of sub-areas. One area is the non-invasive estimation of wall shear stress (WSS) in order to predict possible atherosclerosis, another is aortic wall modeling. These two sub-disciplines are referred to as FSI (fluid-structure interaction), an area of significant international research effort. We are also working with the mechanics of the normal heart, modeling and simulation of vascular trees and bio-inspired robotics.

Division or Group Leader[1]:	Bengt Kasemo
Group also includes Grant Holder[2]:	Julie Gold
Name of Division or Group:	Chemical Physics
University:	CTH

Executive summary

The group has three main research areas: Basic surface science, heterogeneous catalysis, and biointerfaces (relative sizes roughly 2:1:1). The group is international (12 nationalities) with 35-40 people. The common denominators are surfaces, and surface/interface processes and the strong overlap with nanoscience and nanotechnology. Mathematical modeling is small but important. In the biointerface area the groups started with research on dental implants (coll. Brånemark team), particularly characterization of surfaces and controlled preparation. The research diversified into several areas. In the actual reporting period this meant less work on implants, and more in the direction of biosensors, biomolecular adsorption, surface-supported lipid bilayers, and (stem) cell interactions with functionalized surfaces. Biosensing includes both instrumentation (QCM-D) and new detection avenues (e.g. nanoparticle plasmon resonances). The supported lipid bilayer work creates platforms for both the sensing and cell oriented work, and for drug screening (early stage) and targeting (vesicle based). The stem cell work is performed in collaborations with medical/biomedical groups. Collaboration with international groups is frequent, and so is collaborations with industry. Close to 150 journal articles were published in the bio-area. Invited talks were over 40. Both journal papers and talks increased successively during the period. Patents were ca 15. Industrial collaborations exceeded 10.

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Division or Group Leader[1]: Jan Kehr
Name of Division or Group: Section of Pharmacological Neurochemistry
University: KI

Executive summary

The major research interest of our group is focused on the development and applications of techniques for monitoring brain chemical signalling in vivo. Of particular interest are the minimal invasive techniques such as microdialysis with allied analytical technologies and biosensors. These techniques allow studies of chemical neurotransmission and metabolism, as well as other molecules or drugs delivered into the extracellular space of the brain. In vivo monitoring and biosensoring methods provide the closest and the most veritable chemical correlates to behaviour and behavioural models of mental and neurodegenerative diseases. During the last years, we have developed several ultra-sensitive HPLC techniques for determination of atmol levels of monoamines and other classical neurotransmitters (acetylcholine, serotonin, noradrenaline, dopamine, histamine, Asp, Glu, Gly, GABA) in brain microdialysates. Recently, we have initiated a series of studies on applications of functionalized superparamagnetic iron oxide nanoparticles as specific contrast enhancers in magnetic resonance imaging (MRI). Initially, we focus on nanoparticle-based labelling and tracking the stem cells transplanted into the brain or the spinal cord and on labelling amyloid plaques - the hallmarks of Alzheimer´s disease. In addition, our in vivo monitoring techniques will allow studies on controlled drug release from specially-designed nanoparticles aiming for brain targeting.

Division or Group Leader[1]: Stefan Klintström
Name of Division or Group: Forum Scientium
University: LiU

Executive summary

Sensing Science Research and Technology aimed at new applications in medicine, biotechnology and environmental technology. The graduate school Forum Scientium has increased the cooperation between research groups within biomedical engineering at Linköping Institute of Technology (LiTH) and the Faculty of Health Science (HU) both at Linköpings universitet.

Division or Group Leader[1]:	Hans Knutsson
Group also includes Grant Holder[2]:	Magnus Borga
Name of Division or Group:	Medical Informatics (Image Science)
University:	LiU

Executive summary

Research is directed towards the development of adaptive techniques for representation, processing, presentation and visualization of medical images, data and knowledge. A number of graduate and undergraduate courses are given within the field of Medical Informatics. The group is a core partner of the European FP6 NoE SIMILAR and an integral part of CMIV (The Center for Medical Image Science and Visualization) in Linköping. The amount of information that can be tied to a patient is rapidly increasing. Methods to extract the relations that are pertinent in a given situation and to present them in a way that is simple to understand is will be crucial components in future health care. To develop principles and methods for such solutions is the overall goal of the research of the group. On a more detailed level the research group focuses on the development of systems for medical image (e.g. MR, CT and US) analysis. Here the group focuses on theoretically advanced methods for volume and volume sequence processing and the work is directed towards finding unified mathematical tools. The basic theoretical tools come from linear algebra, signal- and information theory, central concepts are e.g. tensors, manifolds, mutual information and canonical correlation. We apply this knowledge to novel imaging applications within the field of biomedical engineering. This mix of theory and applications has been very fruitful and we believe it will continue to be so in the future.

Division or Group Leader[1]:	Johan Kärrholm
Name of Division or Group:	Joint Replacement and Radiostereometry Unit
University:	GU

Executive summary

We have developed radiostereometry (RSA), a method used to perform accurate measurements of skeletal and implant motions in 3-dimensions. Implant and joint motions can be determined in detail.

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2 Some of the Grant Holders that were asked to submit background reports chose to use the option to report jointly with another Grant Holder, with the latter as the "official" submitter of the joint report, called Grop Leader. See Evaluation Process for further details.

Possible associations between motion and pain in the shoulder or low back are studied. One of our main purposes is to make RSA user friendly and intelligent. This has been achieved by implementation of digital radiography and development of new mathematical algorithms and image processing processes. This has facilitated worldwide use and conduction of larger clinical studies. Visualisation of data based on combined RSA, MRT or CT imaging has enabled dynamic studies of skeletal motions based on individual patient data, which opens up a new field for diagnostics and postoperative evaluation. We are participating in the development of international standards for RSA. Our main clinical studies focus on fixation and wear of new implants and especially in situations where the development of new technology is needed. Examples are measurements of wear of total knee arthroplasty, visualisation of "true" joint motion and RSA with reduced number of radiopaque markers. Our way to evaluate new implants and surgical methods has proven very cost effective. The number of patients being included in a study and exposed to the potential hazard of a new implant is reduced. We have also developed algorithms for clinical introduction of new implants, which have drawn much attention internationally.

Division or Group Leader[1]: Håkan Lanshammar
Name of Division or Group: Biomechanics
University: UU

Executive summary

The main focus of the research has been and still is to develop clinically useful methods for measurement and analysis of human motion, with emphasis on the lower extremities. The methods can be used to improve diagnosis and treatment assessment in many important areas, such as orthopaedic surgery, neurology, children rehabilitation and habilitation, and evaluation of prosthetic and orthotic devices. Although this has been an active research area for several decades now, it is only recently that it is becoming feasible to develop methods and techniques that are really clinically useful in a larger scale. Around the world there are hundreds of laboratories where motion analysis is used, but it is still expensive and time consuming. Therefore the use is not exploited to its full potential. In our group we have gradually been moving towards the use of marker less motion systems. By avoiding markers on the body it will be much simpler to do motion measurements, and our aim is to develop methods that does not give lower precision that the present marker based systems.

Division or Group Leader[1]: Anders Lansner
Group also includes Grant Holder[2]: Sten Grillner
Name of Division or Group: SANS
University: KTH

Executive summary

The research of the SANS group (now CBN – Computational Biology and Neurocomputing) is mainly concerned with mathematical modelling and numerical simulation of different brain systems and functions, ranging from detailed modelling of the biochemical networks underlying cellular and synaptic function to large-size neuronal networks comprised of detailed as well as reduced, connectionist model neurons. The former are primarily driven and constrained by detailed biological data whereas the latter are driven more by a top-down perspective. The latter are also serve as valuable inspiration for development of brain-inspired algorithms and technology. At the subcellular level we study the biochemisty of learning rules and synaptic plasticity as well as glucose-insulin secretion coupling in the pancreatic beta cell ("systems biology"). At the cellular level we study mechanisms behind working memory in the medial temporal lobe. At the network level, the microcircuits and neuronal networks underlying spinal and brainstem control of locomotion, behaviour selection (i.e. biological decision making), and cortical associative memory, are being studied. We also develop scalable algorithms for distributed computing based on abstractions from our cortical modelling work, i.e. brain-inspired algorithms. The group has also engaged in the design and use of advanced modelling tools, e.g. simulators for large-scale neuronal network simulations as well as for neuro-mechanical simulations.

Division or Group Leader[1]: Thomas Laurell
Group also includes Grant Holder[2]: Kjell Lindström, Johan Nilsson and Hans W Persson
Name of Division or Group: Electrical Measurements
University: LU

Executive summary

The department has a long-standing record in medical ultrasound dating back to the first real time ultrasonic recordings of heart valve movements

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in 1953. Current efforts in this area target the groups recent discovery of ultrasonic monitoring of longitudinal vessel wall movements. Research is also directed towards fluid flow measurements in complex media, especially blood perfusion in tissue and ultrasonic back scattering modes from ultrasonic contrast agents for improved perfusion measurements. Further ultrasonic research covers non perturbing measurement modes of ultrasound fields utilising optical diffraction tomography. Also, new ultrasonic microarray transducer technology offering synthetic aperture 3D-imaging is under development.

The department also has an extensive research programme within biomedical microtechnology and nanobiotechnology targeting clinical needs. The group has recently pioneered a microchip based ultrasonic standing wave blood washing technology that now is under development as a generic platform for intraoperative blood washing, blood banking and cell differentiation applications. Based on the microfluidic and microtechnology expertise in the group new concepts for vastly simplified and improved bioanalysis in masspectrometry based peptide and protein identification have been developed utilising e.g. inkjet chemistry and nanovial technology. Along this line fundamental microchip developments for catalytic biosensors have been developed and new protein microarray chip substrates offering both fluorescent mode of detection and masspectrometry readout are being pursued. The group is currently also developing implantable neural microchips for neural signal recording and stimulation, aiming at a new mind controlled prosthesis concept that also offers a sensoric feed-back to the patient. Within this project has also a multi site EMG recording system coupled to an neural network signal processing system for an 18 degree of freedom prosthesis control been realised.

Division or Group Leader[1]:	Arne Leijon
Name of Division or Group:	Hearing Technology
University:	KTH

Executive summary

Psycho-acoustical methods to analyse and document normal auditory functions and consequences of hearing impairment. Mathematical modelling for estimating auditory and audio-visual transmission capacity for phonetic speech information. Theory and mathematical models for individual optimisation of signal processing in hearing aids, allowing a combination of speech intelligibility and sound quality as optimisation criteria. Signal processing algorithms for hearing aids. Psycho-acoustical methods for evaluating the benefit of signal-processing algorithms in hearing aids and cochlear implants.

Division or Group Leader[1]:	Lars Lidgren
Name of Division or Group:	Dept of Orthopedics, Clinical sciences
University:	LU

Executive summary

The program has substantially contributed to: the development of new functional biomaterials for structurally organized cartilage and bone tissues that contribute to the quality of life. Combining the different scientific areas in an integrated multidisciplinary taskforce, the chain of knowledge from materials to biology and human application has been well covered, and resulted in several granted patents and extensive industrial applications. www.or.lu.se.

Division or Group Leader[1]:	Kaj Lindecrantz
Name of Division or Group:	Biomedical Engineering Group
University:	HB

Executive summary

With an engineering tool box containing all relevant tools of an electrical engineer we approach different clinical and medical research task were we are convinced that we can contribute. In engineering terms we specialise in signal processing and systems engineering, and also on the neighbouring field of IT. Successful work in medical signal processing will always depend on a deep knowledge from origin of the signal to clinical interpretation and utilisation of the extracted information, and everything that we do is done in close collaboration with medical/clinical professionals and researchers. Collectively we cover the chain clinical problem – underlying physiology –> measurements –> signal preprocessing –> information extraction –> interpretation –> clinical utilisation. We maintain sufficient skills in electronics etc. to make it possible to design and modify experimental equipment to allow studies needed to understand physiological basics behind the phenomena seen in the clinic. We keep up to date with current regulations so that we can get access to signals from interesting patients. The fact that we start with a clinical problem and finish with clinical utilisation is crucial for a prospering cooperation with clinicians. We have many interesting and fruitful discussions and the clinicians know that in return for the signals that we get, we will give new aspects of interpretation and clinical useful monitoring and diagnosis methods.

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Division or Group Leader[1]: Peter Lundberg
Name of Division or Group: MR-unit
University: LiU

Executive summary

Our main research has been directed on pursuing investigations and developments in the field of functional magnetic resonance, with a particular focus on magnetic resonance spectroscopy and functional magnetic resonance imaging. Our driving force has been to be instrumental in the paradigm shift of magnetic resonance methods from qualitative to quantitative magnetic resonance applications. This will be a very fruitful field of MR-research in the future - something that many scientists presently do not realize. In a way quantification will be the 'magnetic resonance of the 21st century'!

Division or Group Leader[1]: Göran Lundborg
Name of Division or Group: Dept of Hand Surgery
University: LU

Executive summary

The group has a unique profile since it represents several faculties and groups within Lund University such as clinical medicine, cellular biology, nano-technology research and cognitive science.

Division or Group Leader[1]: Ingemar Lundström
Name of Division or Group: Division of Applied Physics
University: LiU

Executive summary

The research reported here corresponds to about 15 % of the research at the Division of Applied Physics. The "subgroup" formed to explore the computer screen photo-assisted technique (CSPT) and its immediate as well as future uses is multidisciplinary and contains thus both microbiologists, pharmacologists and applied physicists. There are two major research directions with BME connections which have materialized during the five year period (see part 9 of this section (H) for a statement about the content of the report), namely Computer screen photo- assisted techniques: Physics, technology and applications, and Pigment particle containing cells (melanophores) as information carrying natural nano systems: Biology, physics and biosensing applications. They are parts of the multidisciplinary research performed within the scientific branch of applied physics at IFM, which consists of five research divisions: Applied Optics, Applied Physics, Bio- and Organic Electronics, Biotechnology, and Molecular Physics. The main research directions at the Division of Applied Physics are bio-and chemical sensor science and technology, biocompatible materials, sensor arrays and pattern recognition ("electronic noses and -tongues"). It is involved in the centre of excellence (S-SENCE), three joint strategic research areas for the medical and technical faculties at LiU (diabetes, inflammation, materials in medicine) and the multidisciplinary graduate school Forum Scientium.

Division or Group Leader[1]: Helge Malmgren
Name of Division or Group: ANNIMAB
University: GU

Executive summary

The group is devoted to work on medical applications of learning algorithms. Its main task during the period of evaluation has been to develop a fully automated procedure for segmentation and volumetry of the hippocampus from MRI data. The procedure will be based on a generalisation of atlas based registration methods. Since it is an adaptive method which involves learning, it requires a large data base of manually segmented images. A second task of the group has been the development of a simple and reliable computer-assisted manual segmentation procedure.

Division or Group Leader[1]: Mamoun Muhammed
Name of Division or Group: Materials Chemistry
University: KTH

Executive summary

The main activities involve the fabrication and processing of next generation multifunctional nanoparticles and nanomaterials. The selection of the materials and systems studied is made for specific targeted use or applications. This necessitates the study of the materials properties and understanding basic phenomena associated with size dependence, composition, structure, etc. and undertake a comprehensive characterisation of all

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materials synthesized at different phases. The materials cover a wide range of compositions; including metallic, ceramics, intermetallic, semiconductors, composites as well as polymeric materials. The research involves the development of methods for the synthesis of functional nanoparticles and further processing to nanostructured materials. Several applications are targeted, including structural materials (e.g., steels and hard materials) several functional materials for specific applications; including catalysis, energy generation, nanocomposite for UV or microwave absorption, environment or efficient heat transfer surfaces). In the past five years, biomedical applications of nanoparticles have become an important part of the group activities. The activities started with initial limited funding (2.4 MSEK/3 years) and have rapidly expanded to be a major research area for the group. The research activities cover; developing magnetic nanoparticles as contrast agents for MRI imaging, bio-diagnostics, and controlled drug delivery systems.

Division or Group Leader[1]:	Bo Nilsson
Group also includes Grant Holder[2]:	Rolf Larsson
Name of Division or Group:	Clinical Immunology (Biotechnology)
University:	UU

Executive summary

Innate immunity is fundamental for our defence against microorganisms and other foreign substances and is the basis for the discrimination between self and non-self. A number of different systems exist that contribute to this function of which the cascade systems, NK-cells, PMNs, monocytes/macrophages and platelets are some of the members. The cascade systems of the blood include the complement, the coagulation, the fibrinolytic and the contact systems. In whole blood the cascade systems and platelets can interact with blood cells leading to cell activation, clotting and finally inflammation. Introduction of foreign materials, alien substances or non-blood cells into the blood trigger activation of the cascade systems. It is therefore not surprising to find these systems involved in incompatibility reactions that occur when cell lines and cell clusters, biomolecular constructs or biomaterials used in therapeutic medicine come in contact with blood. Treatment of patients with new treatment protocols using biomaterial devices, drug delivery systems, viral vectors or various cell therapies etc. very often leads to exposure of these devices to whole blood. The resulting activation of cascade systems triggers thrombotic and inflammatory reactions that may sequester or destroy the function of the device. Alternatively, inflammation elicits severe adverse reactions that may affect the outcome of the procedure.

Division or Group Leader[1]:	Håkan Nygren
Name of Division or Group:	Anatomi och cellbiologi
University:	GU

Executive summary

The original quest of the project was "Biocompatibility and toxicity of biomaterials". In recent years we have broadened the concept towards new methods for analysis of lipids and inorganic ions and also narrowed the field of application to the bioengineering of bone resorption. The analytical methods developed by our group are also used in collaboration with groups working on cancer and atherosclerosis.

Division or Group Leader[1]:	Mikael Persson
Name of Division or Group:	Elektromagnetic Bio and Plasma Physics Group
University:	CTH

Executive summary

The group consists of one Professor and seven PhD students. Until year 2000 the research was mainly concentrated towards fusion modelling. Since then we have re-focused the research activities towards medical engineering. In the VR and Wallenberg funded project Medical diagnostics using electromagnetic field we have recently designed and built an experimental micro-wave tomography system which finds and reconstructs dielectric properties of inserted objects. The main focus of the project is on breast cancer imaging but we are presently diversifying towards treatment planning for surgery on epilepsy and microwave sensors and signal processing for on-line monitoring of traumatic brain injuries and hyperthermia. The AFA and EU funded project on dosimetry is concerned with both low and high frequency exposure. New legislation from EU is forcing Sweden to establish laws and the main overall goal of our project is to develop methods that allows for investigations of compliance to these laws. The main overall goal of the project on degenerative medicine is to improve treatment for severe depressions and degenerative neurological diseases. The costs of these

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deceases are staggering with the cost of medication alone exceeding 1 billion. Between 1997 and 2005 the group has published some 30 journal papers and 50 conference papers of which seven where invited. One PhD thesis and four Licentiate theses have been presented in the period. Two PhD theses are scheduled for early 2006.

Division or Group Leader[1]: Bo Risberg
Name of Division or Group: Vascular Engineering Centre
University: GU

Executive summary

The profile of our group has been vascular biology with applied vascular (surgical) implications. Thrombogenicity of the vessel wall has been in particular focus (coagulation and fibrinolysis). Methods have been developed for measurement of fibrinolytic components. Clinically we have pioneered and developed the field of endovascular treatment of aneurysmal disease. During the last 5 years the research has been totally devoted to tissue engineering of blood vessels. Initially we explored basic cell - cell interaction in cells grown in co-cultures of endothelial and smooth muscle cells during static and dynamic flow conditions. By using bioreactors tissue engineered blood vessels have been constructed based on human endothelial and smooth muscle cells with PGA as scaffold. The production of extracellular matrix in the constructs have been exploited. Newer constructs are based on a scaffold of bacterial cellulose developed in our group. Tubes are produced. Cell adhesion and ingrowth both in vitro and in vivo has been analysed. The cellulose is extremely well incorporated in the living tissue. Currently efforts are devoted to produce a compliant scaffold based on cellulose and elastic fibers by electrospinning. Biomechanical testing of the constructs and animal experiments are underway.

Division or Group Leader[1]: Per Roland
Name of Division or Group: Brain Research
University: KI

Executive summary

Cortical dynamics and neuroinformatics entirely directed towards fundamental science.

Division or Group Leader[1]: Camilla Rönnqvist
Name of Division or Group: DIgital X-ray Imaging (DIXI), in Graduate School Advanced Instrumentation and Measurements (AIM)
University: UU

Executive summary

The research area is digital X-ray imaging, where the group has worked along two main lines. One is development of powerful simulation tools to optimize a digital X-ray imaging system in terms of standard imaging parameters. The second line is the development of a hybrid pixel detector for dynamic X-ray imaging. The simulation tool is based on application specific Monte Carlo techniques and evaluates, step by step, the imaging process. To further understand the importance of various effects in the imaging chain, a theoretical model has been derived. Results from the simulation are used as input to the hardware design, and vice versa, measured data from the prototype are used in the simulation package. The detector consists of a semiconductor chip and an electronics chip that contains multiple amplification and readout channels. The chips are connected via a special flip-chip technique. The project requires knowledge in X-ray spectra generation, radiation interaction with matter, semiconductor technology and fast readout. Knowledge about the application is necessary in order to understand the requirements and restrictions regarding parameters such as resolution, speed and dose.

Division or Group Leader[1]: Göran Salerud
Name of Division or Group: Biomedical Instrumentation
University: LiU

Executive summary

The main objective of "Interaction of light with superficial tissue" and "Microscopic and Spectroscopic imaging" (Biomedical Optics Group)" is to study light interaction within biological superficial tissue, such as skin, in order to diagnose not only the specimens status and disease but also to mirror the status of deeper laying tissues and internal organs. The area of research comprises

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modeling of light interaction in tissue through different methods, both in vivo and in vitro, granting the possibility to sample or mimic the optical properties of the tissue. The direction is to develop methods and technologies, useful to determine the tissue viability and processes mirroring physiological actions. This may be achieved by multi-dimensional diffuse reflectance spectroscopy, paired with different type of microscopy, able to study spatial-temporal physiological conditions. Fusioning of video microscopy, laser Doppler perfusion imaging and diffuse reflectance spectroscopy create new possibilities in the study of burns, wound healing process, light therapy and the effect of laser surgery treatment of vascular malformations.

Division or Group Leader[1]:	Örjan Smedby
Name of Division or Group:	Medical Radiology/CMIV
University:	LiU

Executive summary

The Center for Medical Image science and Visualization (CMIV) (http://www.cmiv.liu.se/) is a cross-disciplinary research environment aiming at developing new methods for image acquisition, post-processing and visualization, in close connection to clinical routine and basic medical research. The Center, which has its own premises within the University Hospital, at present comprises around 25 senior researchers and 20 doctoral students from both the medical and the engineering faculty. For the medical radiology group within CMIV, a main research interest is visualization and quantitative measurement of vessels in CT and MR images, including quantitation of atherosclerosis with MRI and image analysis as well as angiographic presentation of coronary CTA. Other current research projects include intraoperative visualization of MRI with mixed reality, clinical and research applications of fMRI, clinical use of volume rendering with CT and MRI, and postmortal CT for forensic purposes.

Division or Group Leader[1]:	Göran Stemme
Name of Division or Group:	Microsystem Technology
University:	KTH

Executive summary

The Microsystem Technology lab (MST) is a part of the department of Signals, Sensors and Systems (S3). Our research is mainly centred around Microelectromechanical Systems (MEMS) and its applications, with a focus on silicon-based applied sensor and actuator technology. Our research staff has developed a significant number of devices with promising performance. The group fabricates its silicon structures and devices at the KTH microelectronics laboratory, comprising 1200m2 of clean room area with all the facilities of small-scale microelectronics and for research on and development of special purpose structures and components in silicon. The group works on applications in the medical field (MedMEMS), the biotechnology field (BioMEMS), optical components (OptoMEMS) and radio frequency signal components (RFMEMS). More information at: http://www.s3.kth.se/mst/

Division or Group Leader[1]:	Tomas Strömberg
Name of Division or Group:	Div Biomedical Instrumentation/Group Circulation and Respiration Physiology Measurement Methods
University:	LiU

Executive summary

The group has developed from application oriented research using engineering tools in understanding microcirculation by combining optical methods such as Laser Doppler Flowmetry and video assisted microscopy or reflection spectroscopy. Clinical studies of microcirculation have been performed at rest, after various provocations in healthy subjects, as well as during leg ulcer healing. Methodological developments emerged from a cooperation in an EU project with researchers from Twente and a research visit to Beckman Laser Institute. We started using Monte Carlo methods for modelling light - tissue interaction and it's effects on Laser Doppler Flowmetry. This led to methods for estimating tissue optical properties, the most fundamental part of biomedical optics. The methods were initially based on probes used in Laser Doppler Flowmetry, using small source - detector distances recording the diffuse reflectance profile. We have widened our knowledge to comprise other methods for estimation of optical properties such as using oblique angle illumination. Presently we develop our own liquid optical phantoms with desired optical properties. Light scattering modelling now includes different phase functions, simulating Doppler shifts and complex geometries. The methods are used to develop quantitative spectroscopy with applications in e.g. assessment of myocardial oxygenation.

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Division or Group Leader[1]: Freddy Ståhlberg
Group also includes Grant Holder[2]: Ronnie Wirestam
Name of Division or Group: MR Physics Group
University: LU

Executive summary

Our research group, which was founded approximately 10 years ago, is active in the field of medical magnetic resonance, with primary focus on development of new techniques for assessment of macrocirculation (flow), microcirculation (perfusion), and thermal molecular motion (diffusion). Macrocirculation/flow: The high intrinsic signal-to-noise ratio at 3T is, in combination with parallel imaging techniques, beneficial for quantitative measurements of flow in coronary vessels and brain cavities such as the cerebral aqueduct. Perfusion: Optimal imaging parameters, contrast agents and doses used in dynamic susceptibility-contrast (DSC) MRI for perfusion studies at 3T are determined, and mathematical algorithms for accurate calculation of perfusion parameters are developed. Non-invasive arterial spin labelling methods for 3T will be developed and compared with the DSC-MRI method. Clinical studies are performed in patients with acute lacunar stroke and brain tumors, and in the evaluation of endovascular neurointerventional procedures. fMRI: Routines for functional cortical activation (fMRI) investigations are optimized at 3T, including careful assessment of the entire fMRI data chain. Methods are developed with improved ability to detect true cognitive activity in the presence of various types of noise. This will have an immediate and widespread impact on, for example, fMRI investigations in epilepsy and in tumor patients. Diffusion: Information about extra- and intracellular water distributions by diffusion measurements is pursued using the high-field gradients available at our 3T systems. Using diffusion data, methods for q-space analysis are developed and new clinically relevant diffusion-related parameters are visualized. Applications encompass patient groups with brain tumors, early dementia and multiple sclerosis.

Division or Group Leader[1]: Leif Sörnmo
Name of Division or Group: Signal processing Group
University: LU

Executive summary

The Signal Processing Group has been active for three decades in the area of biomedical applications, with special emphasis on problems related to cardiology, audiology, neurophysiology, and nephrology. Mathematical modeling and analysis of electrocardiac signals is the main research area, and several novel signal processing algorithms have been developed, implemented, and tested in various clinical settings. Highlights include wavelet-based event sensing in pacemakers, robust detection of micropotentials, ECG-derived respiratory signal estimation, prediction of hypotension during hemodialysis, and noninvasive assessment of patients with atrial fibrillation. The last area is of particular importance as it represents the first approach to characterization of atrial fibrillatory waveform dynamics; the significance of the results is currently investigated and promises to be useful in, e.g., selecting treatment for patients with atrial fibrillation and assessing antiarrhythmic drugs. Several PhD dissertations have been presented at the medical faculty which investigate the clinical significance of the developed algorithms. The research is done in close collaboration with the biomedical engineering industry, having led to several patents. The group has a large network of international collaborators with which signal processing techniques have been developed as well as clinical data collected; the outcome is well-documented through numerous articles.

Division or Group Leader[1]:	Peter Thomsen
Name of Division or Group:	Cell Biology Group, Dept of Biomaterials
University:	GU

Executive summary

The group has a long-term commitment to the study of material-cell and material-tissue interactions using well-characterized and systematically and intentionally modified implant surfaces. A basis for our approach has been the need to gain access to the interface zone under in vivo conditions. Therefore, the development of experimental models, preparation techniques and the application of analytical tools of cell and molecular biology has been a hallmark. The main direction has been towards gaining an increased understanding of the mechanisms of osseointegration and the inflammatory response in association with different material properties. The selection of research tasks have been influenced by, firstly, the long-term collaboration with basic materials science and physics groups, and, secondly, the interaction with clinical challenges, mainly related to the musculoskeletal field.

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During recent years, an applied direction, based on our expertise of models of biocompatibility evaluation, preparation and analysis of implant-related events, has been initiated. This has centered on both providing an expertise for Swedish and international companies, and a transfer of knowledge and own concepts for material surface modification, thereby resulting in the development of second generation of implant products for hard and soft tissue applications. Another recent research line has been the systematic evidence-based analysis of clinical results with oral implants.

Division or Group Leader[1]: Christian Vieider
Group also includes Grant Holder[2]: Peter Norlin
Name of Division or Group: Sensors Group
University: Acreo

Executive summary

Acreo is a research institute owned by the Swedish Ministry of Industry and an industry association. The role of the organization is to support Swedish industrial competitiveness and growth through applied research, development and small-scale production in the fields of electronics and optics. Acreo employs approximately 140 persons, the majority of whom have engineering or doctoral degrees in technical fields. The Sensors Group (sorting under the Industrial Nano- and Microtechnology (INM) department) is, overall, active in the entire field of Microsystem Technology (MST). The group has access to clean-room laboratories equipped with state-of-the-art instruments and process lines for complete MST processes. Since 1992, a major research focus of the group is MST applications in biotechnology and biomedicine ("BioMEMS"), e.g. microsensors, multisensors, and microfluidic systems/lab-on-a-chip. During the years the group has collaborated with several industrial partners, such as Pharmacia Biotech, Biacore, Radi Medical, Datex-Ohmeda, Toolex-Alpha, Applied Sensors and Gyros. Transfer of technology and/or personnel has provided major contributions to the start-up companies Silex, Åmic, Gyros and Gnothis. Since 2000, through European and national grants and in collaboration with Karolinska Institutet, the Sensors group has built a considerable experience in the field of microsystems for neuroscience applications ("NeuroMEMS"), e.g. in-vivo neural recording probes and in-vitro neural cell culture devices. Other current projects are Protein micro arrays, Nanoparticle electrochemical luminescence system, and Sample target for MALDI-MS.

Division or Group Leader[1]:	Peter Wingren
Name of Division or Group:	Projective properties of fractal sets
University:	UmU

Executive summary

Current work within the group follows two main streams. 1) The study of the projective properties of 3D fractal sets when projected to 2D sub spaces (by theoretical studies and by simulations) and 2) application of multi fractal geometry for image analysis of x-ray images in general and mammograms in particular. Progress will open up the possibilities for general applications to organic- and inorganic structures where characterisations of structures are important. The group is interdisciplinary and the sub disciplines are mathematics, mathematical statistics, computer science and medicine/radiology.

The motivation for developing applications of multi fractal geometry methods towards image analysis is that this area is on the threshold from qualitative analysis to quantitative analysis. At the same time the over all focus has changed from fractal- to multi fractal geometry and applications (mass distributions and fractal spectra).

Division or Group Leader[1]:	Bengt Wranne (deceased), Eva Nylander
Name of Division or Group:	Dept of Medicine and Care/Clinical Physiology
University:	LiU

Executive summary

The broad focus of our research group is flow and motion within the cardiovascular system. In a specific sense, we strive to improve the understanding of the complex components and interactions that make up normal and pathological heart function, and to create reliable and quantitative approaches for its study. To reach this goal we use the latest imaging techniques available, and in addition develop specialized tools and methods in-house as the experimental or clinical question requires. By using principles from fluid and solid mechanics on the unique measurement data that we obtain, we can begin, in some cases for the first time, to measure important aspects of physiology that lead to a better understanding of myocardial contraction

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and cardiovascular blood flow phenomena. As a result, diagnostic accuracy and utility are directly effected. The research group is highly multidisciplinary, including physiologists, engineers, clinicians and imaging experts, as well as trainees in many fields. International collaborators have been strategic participants who continue to support the group's work and international presence. The groups has provided the core for the founded Centre for Medical Image Science and Visualization (http://www.cmiv.liu.se).

Division or Group Leader[1]:	Karin Wårdell
Name of Division or Group:	Biomedical Instrumentation – Minimally Invasive Instrumentation
University:	LiU

Executive summary

The research group focuses on biomedical engineering systems for minimally invasive diagnostics and therapy. Activities include modelling and simulation, signal acquisition and processing, experimental in-vitro and invivo prototype development as well as method and instrumentation performance evaluation in clinical settings. The projects are driven by clinical needs in close collaboration with industry and clinical researchers. In the neuro-engineering field the applications are directed towards instrumentation in stereotactic and functional neurosurgery using optical, thermal and electrical methods. Cardiovascular applications include methods for measurements in the myocardium on the beating heart and skin-engineering includes methods to analyse and interpret multiparametic skin data. See also http://www.imt.liu.se/bit/mint/

Division or Group Leader[1]:	Hans Åhlfeldt
Group also includes Grant Holder[2]:	Daniel Karlsson
Name of Division or Group:	Medical Informatics
University:	LiU

Executive summary

The Medical Informatics Group has during the 90th been involved in the EU-projects HELIOS, PRESTIGE and GALEN (GALEN-IN-USE). Our contribution to these projects were methods and systems for data-driven decision support (based on the Arden Syntax), data-driven components of protocols and guidelines, and concept modeling in the domain of surgical procedures respectively. Concept modeling utilized GALEN methods and tools (Terminology Server, GRAIL-language, Intermedicate modeling language). With the experiences and contacts from the early EU-projects as a basis, an application for a Network of Excellence (NoE) entitled "Semantic Interoperability and Data Mining in Biomedicine" [SemanticMining] was submitted 2002. The NoE was funded and we are now coordinating SemanticMining, which is based on the partnership of 25 partners from 11 European countries with approximately 100 identified researchers. For further information about SemanticMining, see www.semanticmining.org. The research activities in SemanticMining are focused around seven areas: – principles in ontology engineering, – evaluation of SNOMED CT, – impact of ontologies on health statistics, – concept systems in laboratory medicine, – the construction of a multi-lingual medical dictionary, – text mining and information retrieval in bioinformatics, – the concept-based electronic health record.

1 Grant Holder who submitted a background report. See Evaluation Process for further details.
2 Some of the Grant Holders that were asked to submit background reports chose to use the option to report jointly with another Grant Holder, with the latter as the "official" submitter of the joint report, called Grop Leader. See Evaluation Process for further details.

APPENDIX 4: BACKGROUND REPORT OUTLINE

International Evaluation of Swedish Biomedical Engineering

Background Report Outline in formatted Panel version, initial letters/ numbers referring to items in original webform

A) Contact data for Leader of Division or Group

H1) Executive Summary of your group's scientific profile and major research directions pursued during the period of evaluation

D) Research area(s)

BME Main area Group's own area - Relative importance

Ba) Staff members

Name, Yr of birth, Title, Staff position, PhD yr, Citizenship, Gender, PhD awarded within the dept?, Period of appointment, Share of BME in academic position % (ditto, Research % and Teaching % of full-time), Grant Holder? (formally), Senior Project Leader? (=SPL; intended for associated leaders in larger Vinnova or SSF projects that dispose significant resources witout themselves being the formal grant holder)

Note from Secretariat: In the original report entered by the groups on the internet, there was a question on possible comments to clinical activity. This question was not very frequently commented and where it was, became too difficult to standardise in the layouted version of the reports. Therefore the answers are best viewed from the database.

H) Scientific Results, Impact etc, for Group as a whole

(1.= Executive Summary – see above = moved to page 1 in layouted version of the reports)

2. Most significant research results and other contributions to scientific knowledge development

3. Most significant contributions to:
   a. graduate education
   b. basic university education
4. Most significant contributions to implementation of the results in:
   a. medical practice and healthcare
   b. other sectors of society
5. Most significant contribution to:
   a. method or technology development
   b. product development
   c. technology transfer to industry
   d. commercial exploitation incl. new companies created on the results of research conducted, etc
6. Most significant contribution to the competitiveness of Sweden
7. Goal fulfilment, etc:
   Reflections as to whether goals have been attained, any major deviations made, things you would have done differently...; views on leadership, etc
8. Which clinical and pre-clinical areas (incl. biology, biotech, etc) benefit from your group's research?
9. Any other comments

Ja) Scientific results per Grant Holder / Senior Project Leader

Name of Grant Holder / Senior Project Leader: NN1, NN2, NN3...

1. Most significant research results
2. Most significant contributions to implementation of the results in:
   a. medical practice and healthcare
   b. other sectors of society
3. Most significant contribution to:
   a. method or technology development
   b. product development
   c. technology transfer to industry
   d. commercial exploitation incl. new companies created on the results of research conducted, etc
4. Most significant contribution to the competitiveness of Sweden
5. Which clinical and pre-clinical areas (incl. biology, biotech, etc) benefit from your group's research?
6. Any other comments

K) Future plans and ambitions for Group as a whole

1. What are your future plans for your group?
   (incl. "succession planning" for senior staff and career planning for younger researchers)

2. How do you envision your own and your group's position in 5-10 years from now?
   a. if funding situation remains approximately as today
   b. if you had, e.g. 50 % more funding
   c. if you had "enough" resources (how much per annum?)
3. How do you envision the position of Biomedical Engineering in Sweden 10 years from now (wide sense)?

L) Extra information (from last page of original webform)

Jb) Comments per Grant Holder / Senior Project Leader

Name of Grant Holder / Senior Project Leader: NN1, NN2, NN3...

1. Strengths and weaknesses of Swedish research in, or close to, your own major area/s:
   a. Strengths:
   b. Weaknesses:
   c. Other comments:
2. In what areas – OUTSIDE your own - would interesting development need to take place in order for your own research to take a leap forward? Justify briefly!
3. Any criticism or recommendations to:
   a. VR
   b. VINNOVA
   c. SSF
   d. All three jointly, (e.g. with regard to the plans for a joint call for proposals in 2006)
4. Other comments addressing:
   a. Swedish industry – (or industry-to-be)
   b. Swedish healthcare sector – (which level?)
   c. Swedish policymakers

D) Research area (s) and leading journals (Group level)

BME Main area (Selected from rolling list of 14 given alternatives + "Other")
Group's own area within main area – Relative importance (1=highest):
Main journals (up to three):

Ca) Grant holder - Publications etc from the time period that the research has been conducted

Name of Grant Holder / Senior Project Leader: NN1, NN2, NN3...

1. (Give number of) Publications:
   A = Total number of articles published and accepted in journals with referee-system

B = Number of conference articles excl. items above
C = Number of review articles, book chapters, books, etc
D = Other publications apart from patents, software etc.

2. Authors, title, journal specifics for up to 12 selected, refereed contributions: Title. Authors. Journal. Full journal data. Funding acknowledged. Reason for selecting this article among the 12 you may list.
3. List all patents (granted & pending), licenses, software, prototypes, products, etc; and indicate what happened to them (customers, users, etc):

Cb) Grant Holder - Financial support during the period 1997-2005

Name of Grant Holder / Senior Project Leader: NN1, NN2, NN3...
Funding body, Total amount kSEK, Total duration, Title of project

E) Degrees awarded and present PhD Projects within Group/Department

Name of Staff member, Start year-PhD/Lic year, Dissertation title, Type of degree. Financing. First position after degree?

F) Cooperation with other parties, Outreach activities

1. Describe the ways your group deploys to inform a wider circle of your activities and results, etc:
2. Describe your group's strategies to facilitate uptake of your research results in academia, industry and society at large:
3. Do you experience any specific obstacles to technology transfer?
4. Current cooperation partners in Sweden and abroad:
   Name of partner, Type of partner [Other academic / Clinical settings / Established industrial companies (SMEs and startups], Country, Contact person,m Objective, Documented output
5. Describe your groups wider clinical and industrial network apart from current cooperation partners as listed in (F 4):
6. List members in the present staff personally involved in a company related to the research going on, as (co)owner, scientific advisor, board members, etc:

G) International exchange of scientists 1997-2005

1. Scientists visiting from abroad for at least one month's duration:
   Incoming visitor, Univ/org, Dept, Country, Duration, Objective
2. Visits to research groups abroad for at least one month's duration:
   Outgoing visitor, Univ/Org, Host, Dept, Country, Duration, Objective
3. Reflections and lessons learned as to international exchanges (good examples; possible problems):
4. In your opinion, who are the leading centres/groups etc in the world in your Group's (sub)area/s? (Leader, Affiliation, Country)

APPENDIX 5: LIST OF DISTANCE EVALUATORS

Adams, Michael A	Queen's University Kingston, Pharmacology and Toxicology, Urology, CA
Berry, Elizabeth	University of Leeds, Medical Physics, now own firm, GB
Coatrieux, Jean Louis	University of Rennes, LTSI-Inserm, FR
El Haj, Alicia J	Keele University Medical School, Institute of Science & Technology in Medicine, GB
Eskola, Hannu	Tampere University of Technology, Digital Media Institute, FI
Forsberg, Flemming	Thomas Jefferson University Philadelphia, Radiology, US
Hall, Laurance D	Retired from University of Cambridge, Herchel Smith Lab, GB
Hoffer, Barry	NIH, NIDA, Baltimore, US
Hubbell, Jeffrey A	EPFL Lausanne, Regenerative Medicine and Pharmacobiology, CH
Jones, Julian R	Imperial College London, Materials, GB
Joos, Thomas	University of Tübingen, Biochemistry, DE
Koudelka-Hep, Milena	University of Neuchatel, Institute of Microtechnology, CH
Malmivuo, Jaakko A	Tampere University of Technology, Ragnar Granit Institute, FI
Niederer, Peter F	ETH Zürich, Biomedical Engineering, CH
Noble, Alison	University of Oxford, Engineering Science, GB
Pyykkö, Ilmari	Tampere University, Ear Nose & Throat Clinic, FI
Roscoe, Sharon G	Acadia University, Chemistry, Nova Scotia, CA
Salathé, René Paul	EPFL Lausanne, STI School of Engineering, CH
Saranummi, Niilo	VTT Information Technology, Human Interaction Technologies, FI
Smallwood, Rod	University of Sheffield, Computer Science, GB
Smith, Peter H S	Northern Ireland Regional Medical Physics Agency Belfast, GB
van Bemmel, Jan H	Erasmus University Rotterdam, Medical Informatics, NL
Verpoorte, Elisabeth M J	University of Groningen, Institute of Pharmacy, NL
von Recum, Andreas F	Ohio State University, Biomedical Engineering Center, US

APPENDIX 6: DISTANCE EVALUATOR'S ASSESSMENT FORM

Distance Evaluator's Report

International Evaluation of Swedish Research in Biomedical Engineering (BME) 1997-2005

Please note that "[...]" below refer to the corresponding headings or items in the Background Reports

Name of Group Evaluation [in statistics, A1]

Group Leader [A2, A3]

Evaluator's a) name and b) main field(s) of expertise + "area code(s)" from last page	**Area codes - see last page!**
a)	
b)	

1. Scientific production, etc [heading Ca].
In view of the share of full-time devoted to BME by Staff members [Ba 12-14] and – as far as you can judge – from the reported funding, how do you assess total scientific production of all Grant Holders taken together?

	5 High	4	3	2	1 Low
a) Volume of publications of relevance to BME (noting that sometimes, total production includes non-BME activities) [Ca + poss. comm. under L]					
b) Quality of 12 selected publications [Ca2]					
c) Volume of patents, licences etc [Ca3], see also 5e below					
d) Ability to secure grants [Cb]					

e) Qualitative comments to a)-d) above for Group as a whole incl. individual Grant Holders. (Ex: Publication records, journals, degree of inter- and multidisciplinarity [Ca, D], Funding mix - VR - VINNOVA – SSF [Cb], etc. *(Enlarge as needed)*

f) Possible comments to d) above, Graduate Education. (Ex: Proportion of students relative to Faculty [Ba], Production of graduates [E], dissertation projects [E4], length of studies [E2-3], first jobs after PhD [E6], etc.) *(Enlarge as needed)*

2. Cooperation and outreach activities [heading F]. Comments as to e.g. level of activity, methods of dissemination, choice and mix of partnerships, outputs, cross-faculty cooperation (engineering + medical), clinical and industrial network, etc. *(Enlarge as needed)*

3. International exchanges [Heading G]. Comments as to e.g. volume, partners, objectives, etc. Do you share the Group's opinions as to "Leading centres/groups" in the (sub) areas indicated [G4]? *(Enlarge as needed)*

	5 High	4	3	2	1 Low
4. Total scientific results obtained by the Group taken together as illustrated by [H2] at Group level combined with [Ja1] at individual Grant Holder or Senior Project Leader level (if the latter have provided individual comments).					

Qualitative comments to the above for group as a whole incl. (major) individual Grant Holders *(Enlarge as needed)*

1(3)

Note: Double arrows below ↔ denote identical questions on Group level [heading H] and individual level [heading Ja]

5. Impact of the research conducted by the Group as a whole as to	5 Major	4	3	2	1 Low
a) Contributions to scientific knowledge development [H2↔Ja1]					
b) Contributions to graduate and basic university education [H3]					
c) Implementation of results in medical practice and health care [H4a↔Ja2, H8↔Ja6], [F4-5]					
d) Laying a basis for utilisation and exploitation of results by existing industry or through formation of new companies [Ca3, H5↔Ja3, F5-6]					
e) Qualitative comments to a) – d) for group as a whole incl. (major) individual Grant Holders. *(Enlarge as needed)*					

6. Future plans and ambitions [heading K] for Group as a whole, with any comments from individuals in [Jb]. Please comment on, e.g. originality and feasibility of plans (in view of intellectual, if not financial, resources available), interest in new scientific developments and directions, etc. *(Enlarge as needed)*

7. Overall evaluation of the Group (Sub-group) in relation to leading groups in the area world-wide.
Please note that the group may represent several differing BME (or sometimes BME + non-BME) research directions, and that some groups are doing basic research whereas others pursue more applied research. Should you prefer so, please copy headline + lines a)–d) below for distinct sub-groups within the Group, naming them after leading Grant Holder. This may also be applied, should your expertise relate to one specific sub-group only.
(Please indicate your assessment of 7a-d below and then go on to 7e!)

7.	5 High	4	3	2	1 Low
a) The scientific quality of the Group as compared to internationally leading groups in the same area(s): 5–1 (Outstanding –insufficient)					
b) Selection (incl. relevance) of research topics: 5–1 (Very well chosen, highly relevant – Mostly mainstream, less obviously relevant)					
c) The capability of the Group to renew research and break new ground in its areas of activity: 5–1 (Highly innovative research – Status quo)					
d) The ambitions of the Group to (prepare for) bringing its own results into practical use. 5–1 (Very high – Insignificant)					

→(Place to paste in possible copies of 7 a-d in case you wish to assess specific sub-group(s) – remember to name them!)

7 e) Qualitative comments to a) – d) for group as a whole incl. (major) individual Grant Holders and sub-groups of the group being evaluated. Highlight strengths and weaknesses. *(Enlarge as needed)*

8. Distance Evaluator's Comments and "Messages" to the Visiting Panel.
Based upon your overall evaluating effort, taking into account *all* Groups / Reports that you have studied, please either here or on a separate sheet, briefly state your opinion of Sweden's standing in the BME AREA(s) that the groups you have evaluated represent. See the 15 areas below, of which the Groups generally have indicated 1-3 on page 1 of their Background Reports. Please note any unique Swedish strengths, identify areas and topics that are weak or need more attention, indicate any specific efforts you would see fit, etc. *(Enlarge as needed)*

9. Evaluator's self-assessment as to	5 High	4	3	2	1 Low
a) Degree of expertise in the engineering area/s of the Group evaluated					
b) Degree of expertise in the medical or clinical areas / aspects concerned					

2(3)

c) Familiarity with conditions for commercial exploitation (where relevant)					
d) Confidence level in assessing this group (sub-group where relevant)					
e) Any other comments. *(Enlarge as needed)*					

10. Declaration of impartiality, date and "signature"

☐ **To the best of my knowledge, I have no direct or indirect conflict of interest in the assessment of this Group / Report**

(Double-click ON box and mark "Select" + "OK", or else write "XX" next to the box)

Any comments as to possible relations with the Group under evaluation:

Place and date:

As we want electronic submission only, please yourself write "Signed by", followed by your name:

To be submitted by e-mail addressed to the person who sent you the "sharp" evaluation material with this Evaluation Form (i.e. normally either Lena-Kajsa Sidén, LKS@stratresearch.se, or Margareta.Eliasson@vr.se (telephone +46-8-50 58 16 73 and +46-8-54 64 41 79, respectively).

Please on page 1, in the box to the right of your name, enter the code(s) that best correspond to your profile

No	BME Area	No	BME Area
1	Biomaterials, tissue engineering	9	Medical informatics
2	Imaging technologies (outside other headings)	10	Medical radiation physics
3	Biomechanics	11	Neuro (biology, engineering, informatics)
4	Biooptics	12	Technical audiology
5	Biosensors, micro-nano-(bio)technologies	13	Therapeutic technologies (various)
6	Cardiovascular	14	Ultrasound
7	Physiological measurement technology and modelling	15	Other
8	Medical image and signal processing		*(Please specify "Other" expertise on top of page 1)*

3(3)

APPENDIX 7: SHORT CV'S OF THE EVALUATION PANEL MEMBERS

Dr. Robert M Nerem

Institute Professor, and Director of the Parker H. Petit Institute
for Bioengineering and Bioscience, Atlanta, Georgia, USA

Dr. Nerem joined Georgia Tech in 1987 as the Parker H. Petit Distinguished Chair for Engineering in Medicine. He currently serves as the Director of the Parker H. Petit Institute for Bioengineering and Bioscience. In addition he serves as the Director of the Georgia Tech/Emory Center (GTEC) for the Engineering of Living Tissues, an NSF-funded Engineering Research Center, and until recently he was a part-time Senior Advisor for Bioengineering in the new National Institute for Biomedical Imaging and Bioengineering at the National Institutes of Health. He received his Ph.D. in 1964 from Ohio State University and joined the faculty there in the Department of Aeronautical and Astronautical Engineering, being promoted to Professor in 1972 and serving from 1975-1979 as Associate Dean for Research in the Graduate School. From 1979 to 1986 he was Professor and Chairman of the Department of Mechanical Engineering at the University of Houston. Professor Nerem is the author of more than 200 publications. He is a past President of the International Union for Physical and Engineering Sciences in Medicine (1991-1994) and also a past President of the International Federation for Medical and Biological Engineering (1988-1991). In addition, he is a past Chairman of the U.S. National Committee on Biomechanics (1988-1991).

Professor Nerem is a Fellow and was the founding President of the American Institute of Medical and Biological Engineering (1992-1994), and he is past President of the Tissue Engineering Society International (2002-2004). He also is Fellow, American Association for the Advancement of Science; Fellow, Council of Arteriosclerosis, American Heart Association; Fellow, American Physical Society; and Fellow, American Society of Mechanical Engineers (ASME). He was Technical Editor of the ASME Journal of Biomechanical Engineering (1988-1997). In 1989 he received the H.R. Lissner Award from ASME, and in 1994 was the ASME Robert Thurston Lecturer. He also was the Konrad Witzig Memorial Lecturer in 1986 for the Cardiovascular System Dynamics Society and the ALZA Distinguished Lecturer in 1991 for the Biomedical Engineering Society. In 1988 Professor Nerem was elected to the National Academy of Engineering (NAE), and he served on the NAE Council (1998 – 2004). In 1992 he was elected to the Institute of Medicine of the National Academy of Sciences and in 1998 a Fellow of the American Academy of Arts and Sciences. In March 1990 Professor Nerem was presented with an honorary doctorate from the University of Paris, and in 1994 he was elected a Foreign Member of the Polish Academy of Sciences. In 1998 he was made an Honorary Fellow of the Institution of Mechanical Engineers in the United Kingdom, and in 2002 received the Pierre Galletti Award from AIMBE. This year he was elected as a Foreign Member of the Swedish Royal Academy of Engineering Sciences. Professor Nerem serves on the scientific advisory board of AtheroGenics, Inc. (Alpharetta, GA) and Tengion (Winston-Salem, NC).

Dr. Stephen Francis Badylak

McGowan Institute for Regenerative Medicine
University of Pittsburgh, PA, USA

Dr. Stephen Badylak is a Research Professor in the Department of Surgery and director of the Center for Preclinical Testing at the McGowan Institute for Regenerative Medicine at the University of Pittsburgh. In 1976, he received his D.V.M. from Purdue University and he completed his M.S. in Clinical Pathology from Purdue University in 1978. Dr. Badylak also holds a Ph.D. in Anatomic Pathology from Purdue University (1981) and graduated with highest honors with a M.D. from Indiana University Medical School in 1985.

Prior to his post graduate training, Dr. Badylak practiced veterinary medicine at a mixed animal practice in Glenwood, Illinois and in Hobart, Indiana. Dr. Badylak began his academic career at Purdue University in 1983 as an Assistant Research Scholar at the Hillenbrand Biomedical Engineering Center.

During his tenure at Purdue University, Dr. Badylak held a variety of positions including Postdoctoral Research Associate (1985) and Associate Research Scholar (1988) and he eventually served as the Director of the Hillenbrand Biomedical Engineering Center from 1995-1998. Dr. Badylak held a dual appointment as an Associate Professor within the Department of Veterinary Physiology and Pharmacology and also practiced medicine as the Head Team Physician for the Athletic Department for 16 years (1985-2001). Prior to joining the faculty of the University of Pittsburgh, Dr. Badylak served as Senior Research Scientist within the Department of Biomedical Engineering at Purdue University and Adjunct Associate Professor of Pathology and Laboratory Medicine at the Indiana University School of Medicine.

Dr. Badylak holds over 40 US patents and 200 patents worldwide and has authored more than 150 scientific publications and 8 book chapters. He has served as the Chair of the Purdue University Tissue Engineering Advisory Board and as chair of several Study Sections for the National Institutes of Health (NIH). Dr. Badylak has either chaired or been a member of the Scientific Advisory Board to several major medical device companies.

Dr. Badylak is a Fellow of the American Institute for Medical and Biological Engineering. He is a charter member and the North American delegate to the Tissue Engineering Regenerative Medicine International Society (TERMIS). Dr. Badylak also holds an Adjunct Professorship at Wake Forest University School of Medicine and at the Wake Forest Institute for Regenerative Medicine and is a member of the Society for Biomaterials. Dr. Badylak is the Associate Editor for Tissue Engineering for the journal Cells, Tissues, Organs. For his contributions to the fields of Regenerative Medicine and Biomaterials, he has been the recipient of awards such as the Sigma Xi Scientific Society 2002 Research Award, the Clemson Award – (Society for Biomaterials) in 2005, Pittsburgh Business Times Hero in Healthcare finalist – 2005, and the Carnegie Science Center Award for Excellence – in 2005.

Dr. Jonathan M. Cooper

Bioelectronics Research Centre
University of Glasgow, Scotland, GB

Professor of Bioelectronics and Bioengineering, Jon Cooper (PhD, Electrical Engineering) with a Chair in Bioelectronics, University of Glasgow. He has interests in exploring the benefits of miniaturisation using micro- and nanotechnologies in order to improve the quality of biological information. Examples of recent work are on the use of ultrasensitive nanocalorimetric sensors in high throughput formats for cell screening, in the development

of new voltage and current clamp electrophysiological techniques and in the implementation of SERRS-on-chip (surface enhanced resonant Raman scattering) as a technique for genomics and proteomics.

Jon Cooper was a member of the Department of Trade and Industry Foresight Lab-on-a-Chip (LOAC) Consortium. He is a principal investigator in the UK's Interdisciplinary Research Collaboration (IRC) in Bionanotechnology, and the UK's IRC in Proteomic Technologies. Over the last 5 years, he has worked with a number of industrial partners including pharmaceuticals, chemical and food/biotechnology companies, including GSK, Pfizer,

Honeywell, Asahi-Kasei (JP), Gene-Logic (USA), MSL, Unilever, Kodak and others.

Among his administrative functions in the UK, Jon Cooper is a member of the Electrical Engineering Panel for the UK Research Assessment Exercise, a member of the Foresight Panel for Infectious Diseases and of the BBSRC "Engineering Biological Systems Research" and "Tools and Resources" Panels. He also sits on the Research Policy Group for the IET.

He is on the Editorial board of IEE Proceedings in Bionanotechnology, and Biosensors and Bioelectronics. He has been elected a Fellow of the Royal Society of Edinburgh (2001), of the Institute of Physics (2003), the Institute of Electrical Engineers (2003) and of the Royal Academy of Engineering (2004). He was a Visiting Professor of Bionegineering at the University of Tokyo, supported by The Ministry of Education, Culture, Science and Sports and Japan Society for the Promotion of Science.

Dr. Richard Kitney
Bioengineering
Imperial College, London, GB

Professor Kitney (DSc (Eng), PhD, DIC) is Professor of Biomedical Systems Engineering in the Department of Bioengineering at Imperial College, London. He is also Deputy Chairman and Technical and Strategic Director of ComMedica Ltd - a medical IT company which recently won the Wall Street Journal Award for Technology Innovation. Professor Kitney has worked in Biomedical Engineering and Healthcare for the last 25 years. He has published over 300 papers in the fields of biomedical signal and image processing, medical informatics and the general application of computers to healthcare. He was the Founding Head of the Department of Bioengineering, Imperial College (1991-2001), and is currently Dean of the Faculty of Engineering at Imperial College.

Professor Kitney has been a member of both British Government and European Commission Committees on the application of Information Technology to healthcare and is involved in the formulation of healthcare policy for the UK and to the EU. He is Chairman of The Royal Academy of Engineering's UK Focus for Bioengineering and recently wrote a major policy paper for the Royal Academy of Engineering (UK) on the Role of Engineering in the Post Genomic Age. He has also been a consultant to a number of major international companies.

Professor Kitney has worked on the study of arterial disease, cardio-respiratory control, biomedical image processing related to magnetic resonance imaging and ultrasound, the development of Picture Archiving and Communications Systems (PACS), and 3D visualisation techniques. Professor Kitney has worked extensively in the United States and has been a Visiting

Professor at MIT since 1991. He is a Co-Director of the Imperial College-MIT International Consortium for Medical Information Technology.

Professor Kitney was made a Fellow of the World Technology Network in 1999 for his innovative work in the fields of health and medicine. He was also made an Academician of the International Academy of Biomedical Engineering in September 2003 (this is the highest honour bestowed by the International Federation of Biomedical Engineering Societies). He was recently made a Fellow of the College of Fellows of the American Institute for Medical and Biological Engineering (AIMBE), and a Fellow of the City and Guilds of London Institute (FCGI). Professor Kitney is also a fellow of the Royal Academy of Engineering, of the Institution of Electrical Engineering and of the Royal College of Physicians of Edinburgh. In 2001 he was awarded the Order of the British Empire (OBE) for services to Information Technology in Healthcare.

Dr. Azam Niroomand-Rad

Georgetown University Medical Center
Washington DC, USA

Professor Azam Niroomand-Rad is Director of Clinical Physics in the Department of Radiation Medicine at Georgetown University Medical School in Washington D.C., USA. She received her PhD in 1978 in Atomic and Molecular physics from Michigan State University, Michigan, USA. She has been working as a clinical medical physicist since 1980 after completing her post-doctoral research in medical physics at the University of Wisconsin, Madison, Wisconsin, USA. She has been certified by the American Board of Radiology (ABR) and the American Board of Medical Physics. She has published numerous articles and book chapters. She is Co-Inventor of a US Patent for designing a novel stereotactic method for treatment of spine lesions. In addition to her teaching, research, and cancer patient care in the Department, she has been very active in the scientific, educational, and professional activities of the AAPM (American Association of Physicist in Medicine) and IOMP (International Organization for Medical Physics).

Professor Niroomand-Rad is recognized by her peers as Fellow of AAPM and as a Diplomat of the ABR. She has organized many international scientific programs in the physics of radiation oncology and has been invited speakers in many conferences. She has helped to promote the status of medical physics worldwide by establishing national medical physics associations as well as organizing workshops and training courses in many developing countries. She has taught as an IAEA (International Atomic Energy Agency)

Expert and has been advisor to many graduate students and residents. She has received the Teacher of the Year Award from the Association of Residents in Radiation Oncology. She is currently serving as Associate Editor of several journals including Medical Physics Journal, International Journal of Low Radiation, Human, Life and Radiation, Iranian Journal of Radiation Research, Kasr El Aini Journal of Clinical Oncology and Nuclear Medicine, Journal of the Egyptian National Cancer Institute. She has served as Chair of the AAPM International Affairs, Chair of the AAPM International Scientific Exchange Programs, and President of the IOMP (2003-2006).

Her research interest includes (but not limited to) photon and electron dosimetry including intensity modulated radiation therapy (IMRT) and CyberKnife robotic linear accelerator, film dosimetry including radiochromic films for interface studies, teletherapy procedures including total body irradiation (TBI) and total skin irradiation (TSI), brachytherapy procedures including high-dose rate (HDR) remote controlled procedures, inter-operative radiation procedures with electron beams (IORT), prostate seed implants with ultrasound guided technique, breast implants including MamoSite technique, intravascular brachytherapy (IVBT) procedures with NOVOST devices.

Dr. Robert S. Reneman

Cardiovascular Research Institute
University of Maastricht, Netherlands

Emeritus Professor of Physiology Dr. Reneman obtained his MD degree at the University of Amsterdam in 1961 and qualified as an anesthesiologist in 1966. In 1968 he received a Ph.D. in Clinical Physiology at the University of Utrecht. In 1970/1971 he continued his training as a basic scientist in Seattle (USA), with the support from ZWO (the Netherlands Science Foundation). In 1974 he was appointed to Professor and Chairman (until October 1990) of Physiology at the Maastricht University.

Dr. Reneman is also Affiliate Professor of Bioengineering at the University of Washington Medical School, Seattle, USA. He is a former president of the European Society for Microcirculation, the Benelux Society for Microcirculation, the Netherlands Society of Physiology and the Federation of European Physiological Societies. He is a member of the Royal Netherlands Academy of Arts and Sciences and the Academia Europea, and foreign corresponding member of the Royal Academy of Medicine of Belgium and a variety of scientific advisory councils. He is a member of the Board of a number of international journals. From 1988-1999 he was Scientific Director of the Cardiovascular Research Institute Maastricht and from 1999-2003 he was President of the Royal Netherlands Academy of Arts and Sciences.

Robert Reneman has received many awards and honours, including Knight in the order of the Netherlands Lion, 1998, Commandeur l'Ordre de la Légion d'Honneur, 2000, Malpighi Award of the European Society of Microcirculation, Stockholm, 2000, Honorary professor Institute for Microcirculation, Chinese Academy of Medical Sciences, since 2000, Member of the Hollandse Maatschappij der Wetenschappen, since 2001. Fellow International Academy for Medical and Biological Engineering, since 2003.

Dr. Reneman also was a Member of the Dutch Health Council, 1987-2002; Chairman of the Commission "Discipline-plan Medical Sciences" of the Royal Netherlands Academy of Arts and Sciences, March 1991-June 1994; Member of the Advisory Council of the Belgian National Foundation for Medical Scientific Research, January 1993-January 1997.

Dr. Reneman is the (co)author of 420 publications in international journals, and 161 books and book chapters.

APPENDIX 8: LIST OF ACRONYMS

AFM	Atomic Force Microscope
ANNIMAB	Artificial Neural Networks in Medicine and Biology Society
AR	AutoRegressive
ARMA	AutoRegressive Moving Average
BAHA	Bone Anchored Hearing Aid
BME	Biomedical Engineering
BMI	Brain-Machine Interfaces
CCD	Charge-Coupled Device
CIS	Clinical Information Systems
CMIV	Centre for Medical Image Science and Visualization in Linköping
CNS	Central Nervous System
COMEX	Characterisation and Optimisation of Medical X-ray Imaging Systems
CORTECH	Swedish universities in cooperation for new cardiovascular technology (SSF framework programme)
CSPT	Computer Screen Photo-assisted Technique
CT	Computerized Tomography
CTA	Computed Tomography Angiogram
CTH	Chalmers University of Technology
DKFZ	German Cancer Research Center
DQE	Detective Quantum Efficiency
DSC	Dynamic Susceptibility-Contrast
ECG	Electrocardiogram
EHR	Electronic Health Records
EKG	Electrocardiogram
EMG	Electromyography
EPR	Electronic Patient Records
EU	European Union
EUV	Extreme Ultraviolet
FFT	Fast Fourier Transform
fMRI	Functional Magnetic Resonance Imaging
FP	Framework Programme
FPT	Fast Padé Transform
FSI	Fluid-Structure Interaction
GABA	Gamma-Aminobutyric Acid
GEM	Gas Electron Multipliers

GU .... Göteborg University
HB .... Borås University College
HIS .... Hospital Information Systems
HPLC .... High Performance Liquid Chromatography
HRRT .... High Resolution Research Tomography
HRV .... Heart Rate Variability
HTS .... High-Throughput Screening
ICR .... Ion Cyclotron Resonance
ICV .... Intracranial Volume
IGS .... Image Guided Surgery
iMR .... Interventional Magnetic Resonance
IMRT .... Intensity Modulated Radiation Therapy
IMT .... Intima-Media Thickness
JRI .... Joint Research Initiative
KI .... Karolinska Institutet
KTH .... Royal Institute of Technology
LDF .... Laser Doppler Flowmetry
LIT .... Light Ion Therapy
LiU .... Linköping University
LU .... Lund University
MALDI .... Matrix Assisted Laser Desorption Ionization
MEMS .... Microelectromechanical Systems
MdH .... Mälardalen University College
MLC .... Multi-Leaf Collimators
MR .... Magnetic Resonance
MRI .... Magnetic Resonance Imaging
MRS .... Magnetic Resonance Spectroscopy
MRSA .... Methicillin Resistant Staphylococcus Aureus
MRT .... Magnetic Resonance Tomography
MST .... Microsystem Technology
MTF .... Modulation Transfer Function
NEQ .... Noise Equivalent Quanta
NIMED .... Competence Centre for Non-invasive Medical Measurements (VINNOVA)
NK-cells .... Natural Killer cells
NMR .... Nuclear Magnetic Resonance
NUTEK .... Swedish Agency for Economic and Regional Growth
PACS .... Picture Archiving and Communication Systems
PDT .... Photodynamic Therapy
PET .... Positron Emission Tomography
PI .... Principal Investigator

PMNs	Polymorphonuclear Leukocytes
PMT	Photomultiplier Tube
PPG	Postprandial Blood Glucose
QCM-D	Quartz Crystal Microbalance with Dissipation
QMRT	Quality Modulated Radiation Therapy
RIS	Radiological Information Systems
ROC	Receiver Operating Characteristics
RSA	Radiostereometry Analysis
SANS	Studies of Artificial Neural Systems
SECM	Scanning Electrochemical Microscope
S/N	Signal-to-Noise ratio
SNOM	Scanning Near-field Optical Microscopy
SNOMED CT	Systematized Nomenclature of Medicine Clinical Terms
SPR	Surface Plasmon Resonance
SSF	Swedish Foundation for Strategic Research
STU	National Board for Technical Development
TEM	Transmission Electron Microscopy
TFR	Swedish Research Council for Engineering Sciences
US	Ultrasound
UmU	Umeå University
UU	Uppsala University
UV	Ultraviolet
VINNOVA	Swedish Agency for Innovation Systems
VR	Swedish Research Council
VR-NT	Swedish Research Council Natural and Engineering Sciences
WSS	Wall Shear Stress
2DF	Two-Degree Field
3-D	3-dimensional
4-D	4-dimensional

Over the years, Swedish researchers in biomedical engineering, together with leading clinicians have contributed several groundbreaking technologies that have successfully competed worldwide.

In order to “diagnose” the status of Swedish biomedical engineering today, the three leading national research funding bodies, the Swedish Agency for Innovation Systems, the Swedish Foundation for Strategic Research and the Swedish Research Council have jointly arranged an international evaluation of Swedish research in the field from 1997 to 2005. In this report a panel of prominent international experts present their findings along with their recommendations to keep Swedish research “healthy” so as to stay at the forefront also in the years to come.

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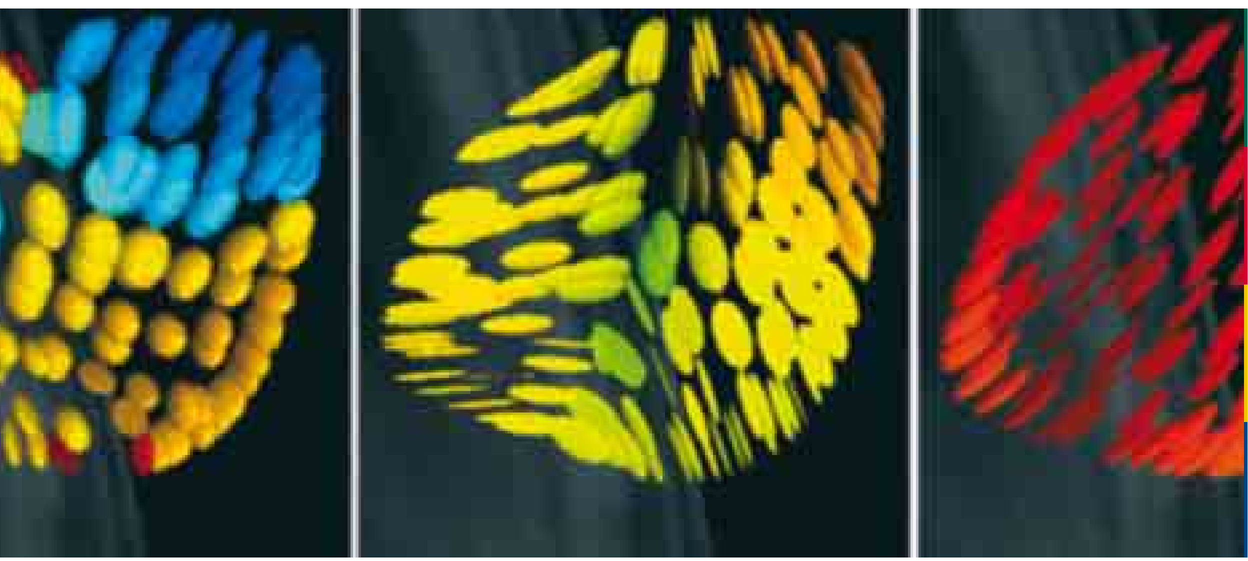

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