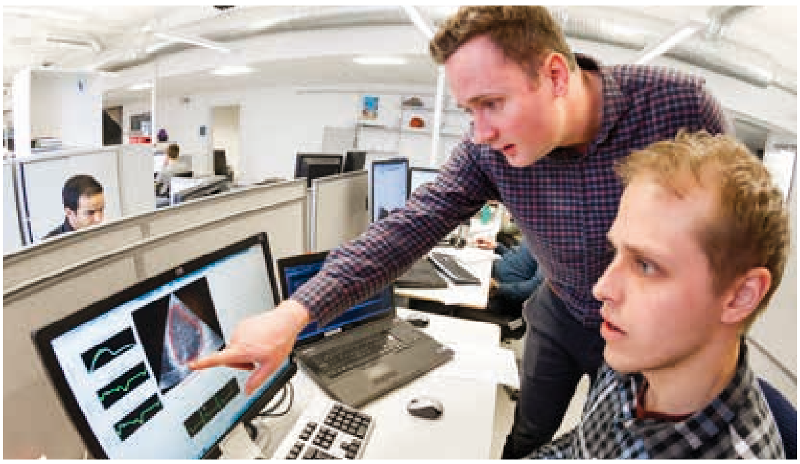
sfi Centre for Research-based Innovation

The Research Council of Norway

MI-Lab

Medical Imaging Laboratory



FINAL REPORT

NTNU

Faculty of Medicine

MI•Lab Final Report

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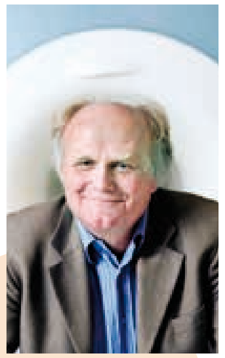
MI•LAB FINAL REPORT

1. FOREWORDS



MI Lab director Olav Haraldseth:

The medical imaging research environment at NTNU/St. Olavs Hospital has a long history of innovation, transdisciplinary research, and collaboration between academia, industry and hospital. Through MI Lab we have been able to further both the quality and quantity of this activity, and in some areas our research and innovation are of top international quality. I am especially proud of how we have created an environment for open innovation and long-term industrial research with high scientific quality and great commitment from the partners. This will be continued and expanded. Some main examples are our new Centre for Research-based Innovation CIUS (Centre for Innovative Ultrasound Solutions), the national infrastructure NorMIT (Norwegian Centre for Minimally Invasive Image Guided Therapy and Medical Technologies), and the unique co-localization of the first clinical hybrid PET-MR system and the first clinical 7 Tesla MRI system in Norway. The latter is part of the national research infrastructure NORBRAIN headed by the Nobel Prize winner Edvard Moser.

On behalf of the host NTNU, Faculty of Medicine dean Bjørn Gustafsson:

For The Faculty of Medicine at NTNU, MI Lab has been an important platform for achieving our strategic goals for research and innovation in medical technology, collaboration with Norwegian industry, and integration with St. Olavs Hospital. The MI Lab experience in building transdisciplinary research environments in collaboration between university, industry and health care is a role model and inspiration for our research and innovation at the Faculty of Medicine. The MI Lab affiliated research groups have been able to attract new external funding from several sources, and the medical imaging research and innovation activity in Trondheim is still growing fast even though the MI Lab funding ceases.

MI Lab Board leader Eva Nilssen from GE Vingmed Ultrasound AS:

Norway has several ultrasound imaging companies that have been successful in the international market, and much of the innovation and the highly competent personnel comes from the ultrasound imaging research environment in Trondheim. MI Lab has been important both to our ability to achieve technological innovation and also for testing new methods in feasibility studies with patients. The MI Lab ultrasound companies are also partners in the new Centre for Research-based Innovation CIUS (Centre for Innovative Ultrasound Solutions). We look forward to eight new years of ultrasound innovation, and we are excited about the CIUS concept of joining forces and exploring synergies between Norwegian health care, maritime and oil & gas sectors that all benefit from ultrasound technology innovation in a wide range of products and applications.

2A. SUMMARY

The Centres for Research-based Innovation (SFI) represent a scheme where several industrial partners, university and hospital work together in an open research environment. MI Lab was able to create a transdisciplinary environment for open innovation and long-term industrial research with high scientific quality and great commitment from the partners in the areas of ultrasound imaging, MR imaging and image-guided surgery.

During MI Lab's lifetime (2007-2015) there have been 276 full scientific papers with MI Lab involvement, 11 inventions considered for patenting, and 45 new and/or improved products and methods for the MI Lab industrial and health care partners. Some of the main research and innovation achievements are presented as success stories on pages 8-23.

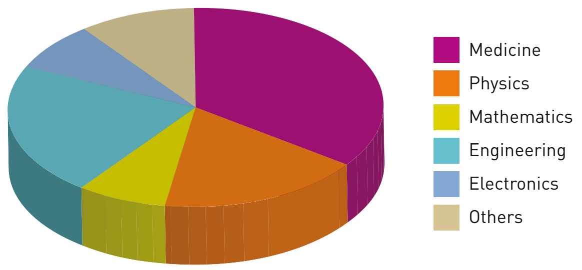
GE Vingmed Ultrasound AS was the most active industry participant and they have identified some opportunities that would not have existed without MI Lab: key product features, clinical research on new methods and applications, and continued idea generation in technology and medicine for potential commercialization in the future.

The other industry partners were small and medium sized enterprises (SMEs) with a high level of competence and expertise in their R&D departments. Even though the resources they could put into the long-term research in MI Lab were limited, they appreciated MI Lab as an important transdisciplinary platform for research on technology and methods relevant to their products and market areas.

MI Lab research and innovation also benefited society through the application in the health care system of new and/or improved products and methods for patient diagnosis, treatment and follow-up. Much of the new technology will contribute to more cost-effective solutions and help provide the basis for a sustainable health care system. St. Olavs Hospital was an active partner in MI Lab, and a broad range of hospital physicians were involved in the MI Lab projects. For St. Olavs Hospital some of the new methods could be applied directly in the daily work without passing through product development by the industrial partners.

MI Lab had a strong focus on researcher training and for the entire eight-year period there will be 32 completed PhDs funded by MI Lab. There were also 19 post doc fellows with funding from MI Lab (some of these were clinical doctors with part-time post doc positions).

The figure shows the transdisciplinarity of this group of 51 PhDs and post docs:



There were also 40 completed PhDs and 16 post docs that conducted their research in connection to the MI Lab projects, resulting in a total of 72 PhDs and 35 post docs involved in MI Lab research and innovation.

The recruitment of highly capable and motivated researchers has been a strong success factor for MI Lab, and within this transdisciplinary research environment there has been a continuous generation of new ideas with potential for fulfilling the MI Lab vision of innovation that may facilitate improved patient outcome and cost-efficient health care, and to help Norwegian industry become successful in the international market. It has been inspiring to see the level of competence and enthusiasm of this group of PhDs and post docs. They obtained medical R&D experience in the intersection of university, industry and hospital, and have proved to be a future pool for recruitment of high-quality personnel for Norwegian industrial R&D, health care and academia.

MI Lab has strengthened the medical imaging research environment in Trondheim (a collaboration between NTNU, St. Olavs Hospital and SINTEF), and has helped increase the focus on innovation and industrial collaboration. This transdisciplinary research environment will be continued and further expanded. Important examples are the new Centre for Research-based Innovation CIUS (Centre for Innovative Ultrasound Solutions), the new national research infrastructure in image guided therapy NorMIT (Norwegian Centre for Minimally Invasive Image Guided Therapy and Medical Technologies), and the new infrastructure for advanced patient imaging with co-localization of the first clinical hybrid PET-MR system in Norway (installed in 2013), and the first ultra-high field 7 Tesla clinical MRI system (to be installed in 2018/2019). The latter is part of the national research infrastructure NORBRAIN headed by the Nobel Prize winner Edvard Moser.

Lists of publications, patent processes, PhD candidates with their thesis titles, and post docs are found in the electronic version of the MI Lab Final Report on: **www.ntnu.edu/milab/annual-reports**.

MI•LAB FINAL REPORT

2B. SAMMENDRAG

Sentre for forskningsdrevet innovasjon (SFI) er en nyskapning der flere industripartnere, universitet og sykehus arbeider sammen i et åpent forskningsmiljø. MI Lab var i stand til å skape et tverrfaglig miljø for åpen innovasjon og langsiktig industriell forskning med høy vitenskapelig kvalitet og stort engasjement fra partnerne innen ultralyd, MR avbildning og bildestyrt kirurgi.

I MI Labs levetid 2007-2015 har det vært 276 fulle vitenskapelige artikler med MI Lab deltagelse, 11 oppfinnelser vurdert for patentering, og 45 nye og / eller forbedrede produkter og metoder for MI Labs industri og helsetjeneste partnere. Noen av de viktigste resultatene fra MI Labs forskning og innovasjon er beskrevet som suksesshistorier på sidene 8 - 23.

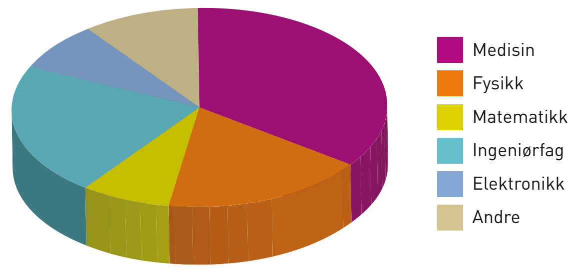
GE Vingmed Ultrasound AS var den mest aktive industripartneren, og de har identifisert noen muligheter som ikke ville ha eksistert uten MI Lab: viktige funksjoner for deres produkter, klinisk forskning på nye metoder og applikasjoner, og kontinuerlig idéskaping innen teknologi og medisin som kan gi nye produkter og nye applikasjoner for eventuell kommersialisering i fremtiden.

De andre industripartnerne var små og mellomstore bedrifter (SMBer) med høy kompetanse og ekspertise i sine FoU-avdelinger. Selv om det var begrenset hvor mye ressurser de kunne sette inn i den langsiktige forskningen i MI Lab, verdsatte de MI Lab som en viktig tverrfaglig plattform for forskning på ny teknologi og nye metoder relevante for deres produkter og markedsområder.

Det var også stor samfunnsnytte fra MI Labs forskning og innovasjon i form av nye og / eller forbedrede produkter og metoder for bedre diagnose, behandling og oppfølging av flere pasientgrupper. Mye av det er teknologi som vil bidra til mer kostnads-effektive løsninger og er med og gir grunnlag for et bærekraftig helsevesen. St. Olavs Hospital var en aktiv partner i MI Lab, og et bredt spekter av sykehusleger var involvert i MI Lab prosjekter. For St. Olavs Hospital kunne også mange av de nye metodene tas i bruk direkte i det daglige arbeidet uten å måtte passere gjennom produktutvikling hos industripartnerne.

MI Lab hadde et sterkt fokus på forskerutdanning og for hele åtteårsperioden vil det være 32 PhD grader finansiert av MI Lab. Det var 19 postdoktorer med finansiering fra MI Lab (noen var kliniske leger med deltids postdoktor stillinger).

Figuren viser tverrfagligheten i denne gruppen av 51 PhD stipendiater og postdoktorer:



Det var også 40 fullførte PhD grader og 16 postdoktorer som drev sin forskning i tilknytning til MI Lab prosjekter, noe som resulterer i totalt 72 PhD grader og 35 postdoktorer involvert i MI Lab forskning og innovasjon.

Rekrutteringen av dyktige og motiverte forskere har vært en viktig suksess faktor for MI Lab, og innen dette tverrfaglige forskningsmiljø oppsto stadig nye og kreative ideer med potensial for å oppfylle MI Labs visjon om innovasjon som bidrar til bedre pasientbehandling og et mer kostnadseffektivt helsevesen, og samtidig hjelpe norsk industri til å bli vellykket i det internasjonale markedet. Det har vært inspirerende å se kompetansen og entusiasmen i denne gruppen av PhD stipendiater og postdoktorer. De fikk FoU-erfaring i skjæringspunktet mellom universitet, industri og sykehus, og har vist seg å være en fremtidig base for rekruttering av høyt kvalifisert personell for norsk industri, helsetjenester og akademia.

MI Lab har styrket forskningsmiljøet i Trondheim innen medisinsk avbildning (et samarbeid med NTNU, St. Olavs Hospital og SINTEF), og har bidratt til økt fokus på innovasjon og industrisamarbeid. MI Labs visjon og aktiviteter vil bli videreført og ytterligere utvidet. Viktige eksempler er det nye Senter for forskningsdrevet innovasjon CIUS (Centre for Innovative Ultrasound Solutions), den nye nasjonale forskningsinfrastrukturen i bildestyrt behandling NorMIT (Norwegian Centre for Minimally Invasive Image Guided Therapy and Medical Technologies), og den nye infrastrukturen for avansert avbildning med samlokalisering av det første kliniske hybrid PET-MR systemet i Norge (installert i 2013), og det første ultra-høy felts 7 Tesla kliniske MR-systemet i Norge (planlagt installert i 2018/2019). Sistnevnte er del av den nasjonale forskningsinfrastrukturen NORBRAIN som ledes av Nobelprisvinner Edvard Moser.

Lister over publikasjoner, patent prosesser, PhD kandidater og postdoktorer er presentert i den elektroniske versjonen av MI Labs Sluttrapport på: **www.ntnu.edu/milab/annual-reports**.

3. ABOUT MI LAB (Medical Imaging Laboratory)

The **MI Lab vision** was to facilitate cost-efficient health care and improved patient outcome through innovation in medical imaging, and to exploit the innovations to create industrial enterprise in Norway.

The **MI Lab research plan** was based on the understanding that the most important challenge to future health care is how to exploit the great achievements in medical research in order to improve patient treatment and outcome while containing costs. Medical imaging is central to meeting this challenge, and new technology for improved cost-efficacy should be a main focus for imaging research and industrial innovation. Innovation in medical imaging can contribute to improved cost-efficiency on several levels, and MI Lab has chosen to focus on three important areas:

- High quality medical imaging products and applications for non-expert users at the initial point-of-care.
- Less complications and more rapid patient rehabilitation with image-guided, minimally invasive surgery.
- More rapid and more precise choice of efficient treatment through decision-making based on advanced medical imaging.

Based on the advice from the MI Lab Scientific Advisory Board, it was decided to have one "area of focus where it can be the synergistic agent for the creation of new programme(s)". MI Lab chose to focus particularly on medical ultrasound integrating basic technology research into hardware and software with clinical feasibility studies.

Inside this framework, MI Lab had the following project structure:

Research Task 1: Ultrasound technology

- Ultrasound image improvement

Research Task 2: Advanced imaging applications for non-expert user

- Cardiac ultrasound
- Pocket-sized ultrasound

Research Task 3: Image guided minimally invasive surgery

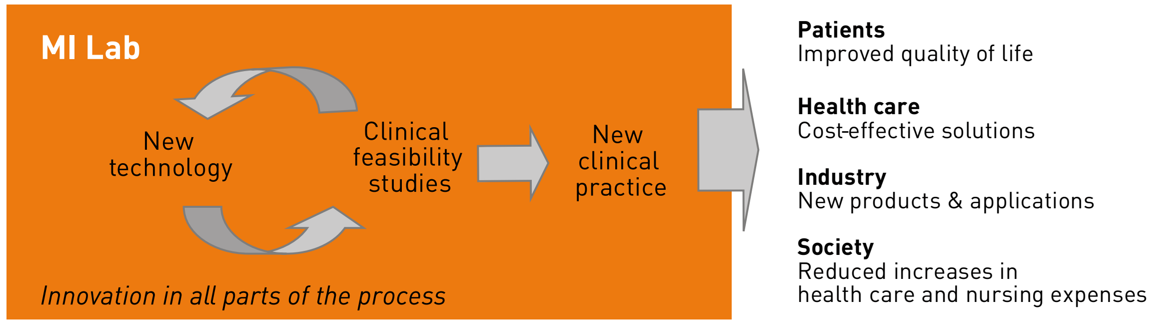
- Neurosurgery
- Cardiac & vascular surgery

Research Task 4: Imaging based information to support medical decision making

- Advanced MRI methods in clinical diagnosis
- MRI in regenerative medicine & nanoparticles for imaging

MI Lab had a broad range of **research and innovation achievements** in all the four research tasks described above. During MI Lab's lifetime (2007-2015) there have been 276 full scientific papers with MI Lab involvement, 11 inventions considered for patenting, and 45 new and/or improved products and methods for the MI Lab industrial and health care partners.

The **MI Lab scientific approach and long-term goals** are summarized in this figure:



The **MI Lab strategy** was to establish a transdisciplinary environment for medical imaging research and innovation by:

- Bringing together researchers from university, hospital and industry on a daily basis.
- Establishing a large multi-disciplinary research environment including medicine, ICT, physics, mathematics, cybernetics, electronics, physiology, molecular biology, neuroscience, psychology etc.
- In the same projects combine curiosity-driven research and relevance for industry and health care.

The **MI Lab partners** (2015) were:

- NTNU (host)
- GE Vingmed Ultrasound AS (industrial partner)
- MediStim ASA (industrial partner)
- NordicNeuroLab AS (industrial partner)
- Sonowand AS (industrial partner)
- Aurotech Ultrasound AS (industrial partner)
- Arctic Silicon Devices AS (industrial partner)
- CorTechs Labs Inc (industrial partner)
- St. Olavs University Hospital (public partner)
- Helse Midt-Norge (public partner)
- SINTEF (research partner)

The **MI Lab board** (2015) consisted of:

- Eva Nilssen, GE Vingmed Ultrasound AS, leader
- Erik Swensen, MediStim ASA
- Morten Bjerkholt, Sonowand AS
- Audun Græsli, Aurotech Ultrasound AS
- Sturla Eik-Nes, St. Olavs University Hospital
- Stig Slørdahl, NTNU
- Asta Håberg, NTNU

MI Lab financial contributions (in MNOK):

Contributor	Cash	In-kind	Total
Host	22 351	13 704	36 055
Industrial partners	8 575	62 104	70 679
Public partners	15 093	9 882	24 975
Research partners	0	11 889	11 889
Research Council of Norway	76 074	0	76 074
Sum	122 093	97 578	219 671

The **MI Lab Scientific Advisory Board** consisted of:

- Professor Peter Burns, University of Toronto, Canada
- Professor Lars-Åke Brodin, The Royal Institute of Technology (KTH), Stockholm, Sweden
- Jean-Francois Gelly, Parallel Design SA, Sofia Antipolis, France
- Professor Henrik Larsson, Unit for Functional Image Diagnostics at Glostrup University Hospital, Copenhagen, Denmark

There was a large group of **MI Lab senior researchers** involved in the different research tasks. Some of the most important are listed below:

- Hans Torp — NTNU — Ultrasound technology
- Lasse Løvstakken — NTNU — Ultrasound technology
- Kjell Kristoffersen — GE Vingmed & NTNU — Ultrasound technology
- Eva Nilssen — GE Vingmed — Ultrasound technology
- Trond Ytterdal — NTNU — US probe electronics
- Asbjørn Støylen — NTNU & St. Olav — Cardiac ultrasound
- Bjørn Olav Haugen — NTNU & St. Olav — Pocket-sized ultrasound
- Geirmund Unsgård — NTNU & St. Olav — Image guided surgery
- Toril A. Hernes — SINTEF & NTNU — Image guided surgery
- Asta Håberg — NTNU & St. Olav — Clinical MR imaging
- Olav Haraldseth — NTNU & St. Olav — Clinical MR imaging
- Tone F. Bathen — NTNU — Clinical MR imaging

It is impossible to describe all the **MI Lab research and innovation achievements** in detail, and we have chosen to present four main success stories (see next chapter pages 8-23).

Lists of publications, patent processes, new and/or improved products and methods, PhD candidates with their thesis titles, and post docs are found in the electronic version of the MI Lab Final Report at: www.ntnu.edu/milab/annual-reports.

Siri Ann Nyrnes examines a small baby using BFI.

Photo: Geir Mogen/NTNU.

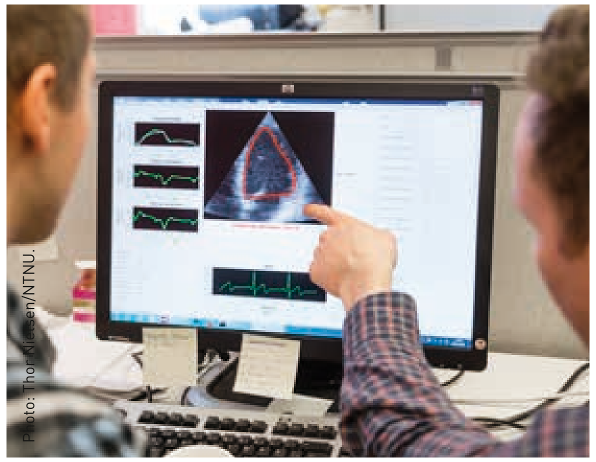
BREAKTHROUGH for tiny hearts

Congenital heart defects occur in various degrees of severity in about 1% of newborns. A common way of diagnosing this is by using ultrasound to look at the blood flow through the heart. But until recently this blood flow was only indicated by colours, requiring a high level of interpretation by the cardiologist.

By improving Doppler ultrasound techniques, it is now possible to both measure and better visualize blood flow in the heart. Cardiologists can now see the direction of the blood flow in detail. This may lead to more accurate diagnoses, and could lead to a better understanding of congenital heart disease.

Professor Lasse Løvstakken at NTNU was working on improving blood flow imaging for many years using Doppler ultrasound machines from MI Lab partner GE Vingmed AS and was looking for opportunities to test it on patients. This put him in touch with paediatric cardiologist Siri Ann Nyrnes at St. Olavs Hospital, a meeting that formed the basis for this MI Lab project, which has focused on blood flow imaging (BFI) in paediatric cardiology.

Through close collaboration – in fact Løvstakken often accompanies Nyrnes when examining patients – it has been possible to improve the techniques and optimize them for the needs of cardiologists. "I see something clinically interesting or challenging and I contact Lasse via SMS or a phone call, and he comes and we look at the child [patient] together. He then goes back to his office and optimizes the machine and gets the most that we can get out of the pictures," Nyrnes says.



Sigurd Storve and Lasse Løvstakken study the ultrasound images.

Professor Lasse Løvstakken.

Photo: Thor Nielsen/NTNU.

"This interaction has been very important in developing this technique." Løvstakken adds: "For me it is very important to be there and see what's going on." They both praise the set-up at St. Olavs University Hospital in which the university is part of the hospital buildings, enabling such close collaboration between technology and the clinic.

Measuring the blood flow

One result of this close collaboration is the development of blood speckle tracking, where one can quantify the movement of the blood flow in any direction. Previously, it was possible to see the blood moving, but the images had a lot of room for improvement. With the new blood speckle tracking technique, it is possible to actually measure the blood flow and its direction, in addition to visualising it. The images themselves are also of better quality due to a higher frame rate (more images per second), and are easier to interpret.

The technique has already been tested on 42 babies in the clinic in a feasibility study, and the results are promising. In fact, they are so promising that the project has received considerable attention both nationally and internationally. This autumn a larger study will take place at the SickKids Hospital in Toronto, Canada using the blood speckle techniques to study more patients with different diagnoses.

The project has also been helped along by improvements in ultrasound technology by industry partner GE Vingmed. "The project has progressed in step with our development of improved methods, and with industry's improvement of the scanners. We rely on using very modern equipment," Løvstakken says. "As new generations of machines become available, we are able to do new things."

Løvstakken calls blood flow imaging and blood speckle techniques the next generation of Doppler imaging. Although the quality has improved over the years, the fundamental clinical information from Doppler images has been more or less at a stand-still since 1985.

Breakthrough in paediatric echocardiography

Although the technological improvements are noteworthy in themselves, both Løvstakken and Nyrnes believe the potential clinical usefulness is the biggest achievement of the project.

"I'm quite convinced that this method will improve diagnostics in the future.. But the most important thing is that it may help us understand physiology better, although that will take further studies to document," Nyrnes adds. "We believe this is a new breakthrough in paediatric echocardiography."

Nyrnes explains: "It's quite a big step forward to see the blood flowing like this. We may now perhaps be able to understand how congenital heart defect develops, for example."

A bonus outcome is also that the improved images are much more intuitive, meaning that it is easier to convey information not only to medical students, but also to patients and their families. One no longer needs years of cardiology experience to see how the blood flows through the heart.

Photo: Thor Nielsen/NTNU.

Working on improvements.

Blood speckle patterns

are added on top of the colour Doppler showing the blood flow along and across the ultrasound beam. It makes it possible to quantify and visualize complex flow patterns with a higher accuracy than traditional Doppler, which only assesses whether the blood is moving towards or away from the ultrasound probe.

The technique is based on a custom, ultra-high frame rate imaging set-up, through which it is possible to perform 2D tracking of blood image patterns over time.

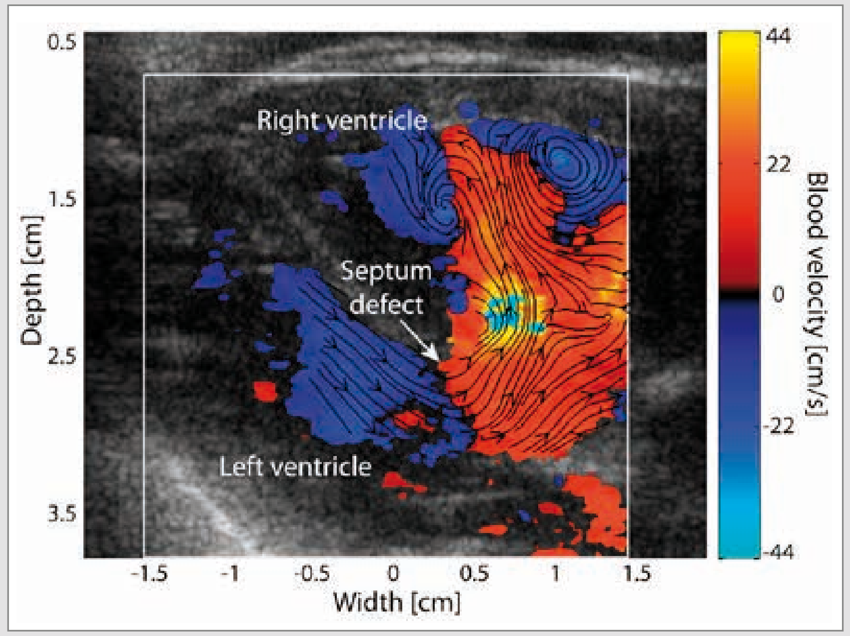


Photo: Lasse Løvstakken.

The image shows the blood flowing from the left and into the right ventricle of the heart due to congenital heart disease (ventricular septal defect). The arrows on top of the colour Doppler illustrate how the blood flows through the opening in the heart wall and forms vortices in the right ventricle.

In summary, under the MI Lab umbrella, the blood flow imaging technique has been taken from its early stages and developed further. It has gone through feasibility studies, been further improved and is now at a stage where it is ready for larger studies.

And if cardiologists such as Nyrnes get their dreams fulfilled, the techniques will become even easier to use for the clinicians. One day it may be possible to get the information in real-time at the patient's bedside, rather than requiring analysis back in the office.

PhDs

SIRI ANN NYRNES, *New ultrasound flow modalities for evaluation of congenital heart defects*, 2014.

SOLVEIG FADNES, *Two dimensional blood velocity estimation for intracardiac flow assessment*, 2014.

Blood speckle tracking has already been tested on 42 babies, and the results are promising.

POCKET-SIZED ULTRASOUND changes clinical practice

Ultrasound is non-invasive, readily available and does not involve any form of radiation, but until recently specially trained personnel and high-end systems have been required to perform examinations such as echocardiography. The systems are expensive, can weigh more than 100 kg, and are not easily moved.

With the pocket-sized, handheld, ultrasound device Vscan, it is possible to do 10-minutes examinations at the bedside, which leads to improved diagnostic precision and improved workflow with patients, thereby reducing suffering and health care costs.

The Vscan has been developed by GE Vingmed Ultrasound AS, Horten, Norway, in cooperation with St. Olavs University Hospital.

Easier for non-experts

After the launch of Vscan in 2009, GE Vingmed Ultrasound wanted to develop the software further and to identify clinical scenarios for Vscan. "The main focus of this MI Lab project was to make it easier for non-expert users to use ultrasound, and to test it in a variety of clinical scenarios to see if it could help clinicians in their everyday work both in hospitals and in out-patient settings among GPs [general practitioners]," NTNU professor and cardiologist Bjørn Olav Haugen explains.

"The process has been an interactive one where engineers develop something in cooperation with us clinicians, reconciling our demands with the technical possibilities." One result of this is that the engineers developed software that enables the Vscan to record ultrasound images without a lot of extra equipment such as ECG cables. "This makes it much easier to carry these machines in our pockets and to simply start scanning."

Photo: Geir Mogen/NTNU

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About Vscan

The Vscan weighs less than 400 g and fits easily in a hospital coat pocket. It allows fast, simplified and accurate investigation of various organs such as the heart, including echocardiography without relying on ECG cables. The examinations can be done by the bedside or outside of hospital.

Vscan has been developed by GE VingMed Ultrasound (Horten, Norway) in cooperation with NTNU and St. Olavs Hospital. It was launched in October 2009.

Photo: Geir Mogen / NTNU

Changed clinical practice

Haugen and his colleagues Ole Christian Mjølstad (NTNU /St. Olavs Hospital), and Håvard Dalen and Garrett Newton Andersen (NTNU/Levanger Hospital) have conducted clinical studies with users ranging from cardiologists to medical residents and general practitioners. The results have been uplifting despite some resistance in the beginning:

"We met a lot of scepticism among colleagues, who were afraid that we might miss something, that this looked 'too easy'. But we did it anyway and the findings were quite surprising," Haugen says. "Now 'everyone' seems to use it, at least in hospitals. So we have really changed clinical practice."

One of the clinical studies found that adding a 10-minute pocket-sized ultrasound session to the standard patient examination, cardiologists corrected the diagnosis in almost 1 out of every 5 patients, resulting in a completely different treatment strategy for many of the patients, without delays.

"By adding the use of Vscan to standard, clinical practice, we found more pathology among patients admitted to hospital, and we spent no more than 10 minutes doing so," Haugen says.

A similar study with medical residents found that spending around 10 minutes examining the patients with the Vscan, they were able to correct, verify or add important diagnoses in more than 1 of 3 emergency medical admissions. "Which is perhaps even more important, because it is they who are in the front line," Haugen explains.


Professor and cardiologist Bjørn Olav Haugen.
Photo: Thor Nielsen/NTNU.

Minimal training

General practitioners have also been able to use the Vscan to carry out simplified assessments of, for example, the left ventricular function of the heart. Medical students with minimal training have been able to obtain acceptable, relevant organ recordings and interprete these with great accuracy, indicating that pocket-sized ultrasound like the Vscan can be used as a diagnostic tool by non-experts.

"For me, as a physician, this is something I have hoped for, for years – especially in the ER [emergency room] where it often is not clear whether a case is due to pulmonary or cardiac disease, and you have to make an educated guess. By adding Vscan for just a few minutes, you can see what's really going on. It is a small revolution really!"

Research continues with more clinical studies and with regard to technological developments by industry. There are also plans to use Vscan more extensively in the training of the next generations of medical students.

Awards

14th Most Important Invention World Wide, *Time Magazine*, 2009

Engineering Feat of the Year, *Teknisk Ukeblad*, 2009

Best Scientific Paper in 2013 to Ole Christian Mjølstad MD PhD due to impact on current clinical practice, *St. Olavs Hospital*, 2013

Central Norway Regional Health Authority Research Award to Håvard Dalen MD PhD, *Central Norway Regional Health Authority*, 2014

PhDs

OLE CHRISTIAN MJØLSTAD, *Pocket-size ultrasound, a new diagnostic tool in clinical practice*, 2013

GARRETT NEWTON ANDERSEN, *Point-of-care pocket-size ultrasonography – bringing the diagnosis back to the bedside*, 2015

Ole Christian Mjølstad and Hans Torp demonstrating the Vscan.


Photo: Thor Nielsen/NTNU

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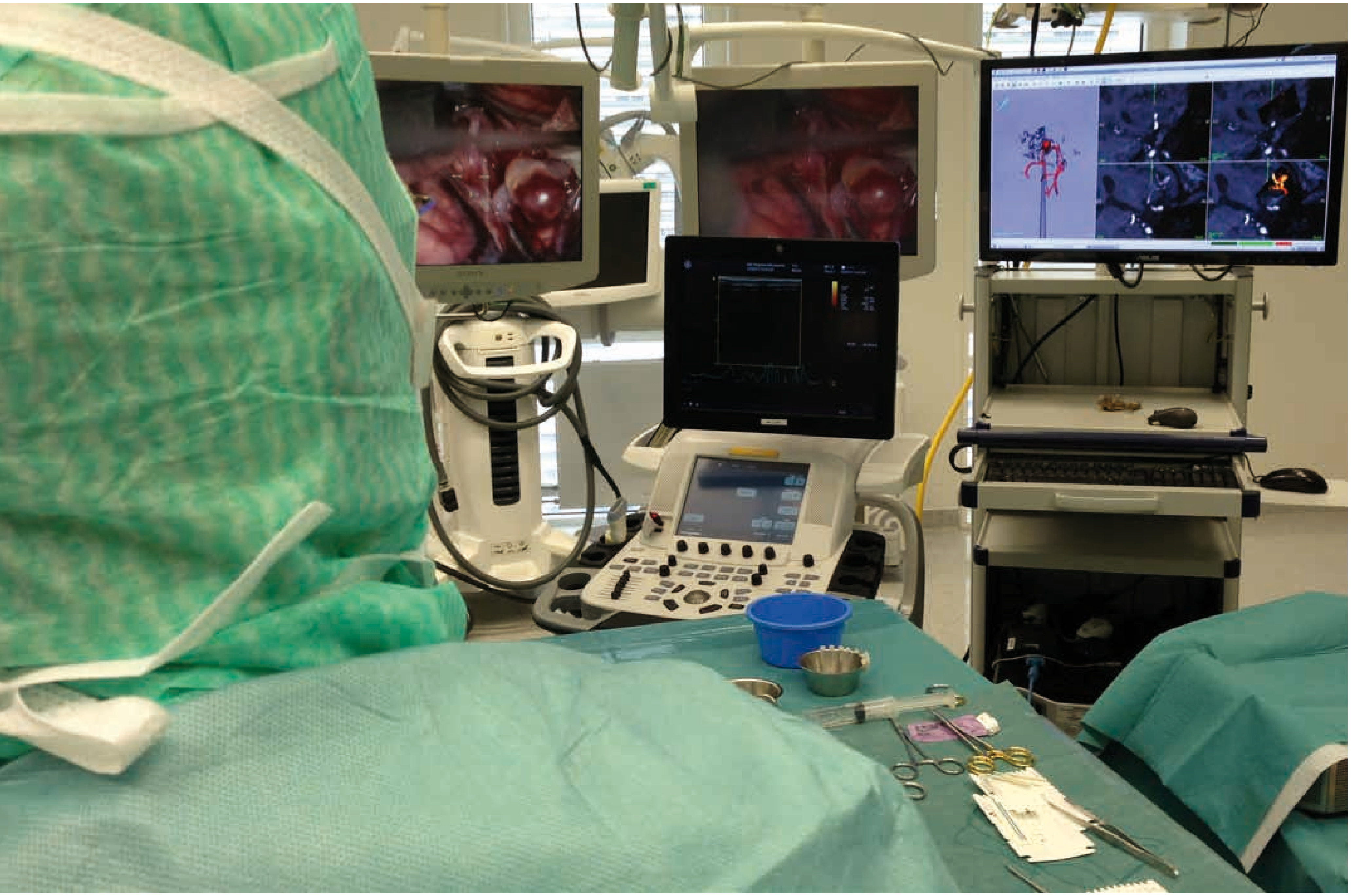
Ultrasound aids BRAIN SURGERY

How do you remove a raisin from a vanilla pudding – without destroying the pudding? While most people might answer "you should just eat the whole thing", a neurosurgeon faces this near impossible task every time he enters the operating theatre.



With the new system, ultrasound is used to continuously update the pre-surgery MR images during surgery.

The brain, with all its wirings and functionally different areas, has very few visible landmarks to navigate a surgeon's tools by. That's why MR images are used to locate tumours before the surgery. However, since the brain is soft like pudding, and the patient is positioned differently on the operating table than in the MRI machine – the anatomy of the brain will change position during the operation. The surgeon needs updated images to manoeuvre between functionally critical areas and neural signalling highways.

Intraoperative MRI, getting new MR images during surgery, has been an option. However, it is time consuming and therefore more risky for the patient, to be wheeled out of the operating theatre, placed into the MRI machine while under anaesthetics, before being wheeled back again. A quicker, and as it turns out even better solution, is to use ultrasound.

Updates images during surgery

Neurosurgeon and professor Geirmund Unsgård at St. Olavs Hospital and NTNU, and engineer and research manager Tormod Selbekk at SINTEF have worked together with their colleagues in their research group to develop high-quality, real-time images to aid the surgeon. Together with post docs and PhDs supported by funding from MI Lab, they have now arrived at a new system where the MR images from before the surgery can be updated continuously during surgery. This will compensate the offset caused by the patient's position and surgical work, and give the surgeon a more precise map.

"We use the ultrasound probe with a navigation system that works almost like GPS, to get updated images at different stages of the surgery," Selbekk explains. "For instance, after Unsgård has removed a piece of the tumour, the surrounding tissue may have shifted its position. The ultrasound will give us updated images of the brain to reflect this. We explore algorithms that will tweak the pre-surgery MR images into updated ones based on the input from the ultrasound. This way the surgeon can see how much of the tumour has been removed, and where to cut next."

Changing the image of brain surgery

Geirmund Unsgård was the first surgeon to ever use the concept of 3D ultrasound as a guide in brain surgery. His debut of using 3D ultrasound

Photo: Geir Mogen/NTNU.

Geirmund Unsgård was the first surgeon to ever use the concept of 3D ultrasound as a guide in brain surgery.

n Terje Heilgren Hansen.

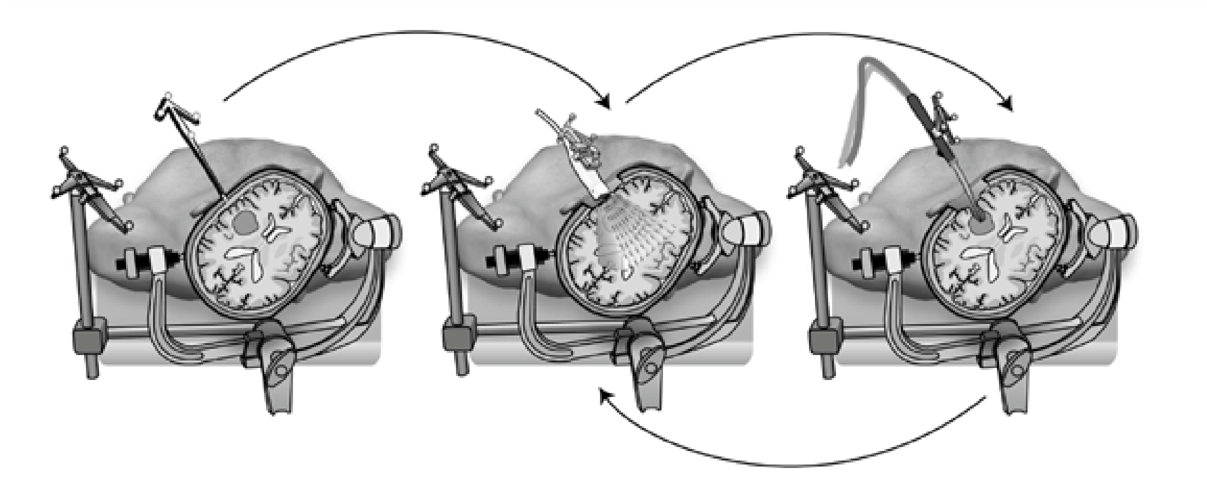
Mapping a moving landscape

Here's the challenge. A brain is as soft as pudding, and about as sturdy. It sits inside the scull and three meningeal layers, hard and soft membranes that keep the brain in place among other responsibilities. Together they cushion the brain that lies submerged in cerebrospinal fluid. When you move or tilt your head, the brain will shift its position slightly. The MR images are made while the patient lies on his or her back, head tilted slightly backwards. During surgery, the patient may be belly down, head on the side – depending on the location of the tumour and chosen entry point. The relative position of the brain to the skull may be offset. Intraoperative ultrasound imaging is used to provide updated images of the brain throughout the surgery.

was back in 1996, and over the years he has refined the method in collaboration with fellow surgeons, engineers and scientists at NTNU, SINTEF and St. Olavs Hospital in Trondheim.

"Brain surgery is a bit like moving in a dark landscape that changes as you move forward," Unsgård says. "Everything you touch has a vital function. Your map and your experience is what help you to limit the damage. The ultrasound updates to the MR images are vital to help me minimize damage to the healthy parts of the patient's brain – to make sure we do not remove more than we need to."

Another benefit of using ultrasound for navigation purposes and to provide updated images instead of MR is the time aspect. Ultrasound takes less time than intraoperative MRI, and in brain surgery, which often lasts five to eight hours or more, this means less risk of fatigue for the surgeon.



The anatomy of the brain changes position during surgery and the surgeon therefore needs updated images to manoeuvre between functionally critical areas and neural signalling highways.

Increased survival rate

"A very encouraging result is that our method using early surgical treatment with the aid of ultrasound and navigation technology seems to increase the life expectancy for patients with malignant but less aggressive brain tumours (low-grade tumours)," Unsgård says.

Surgeons often prefer a conservative approach to lower the risk for the patient – a 'watch and wait' strategy until the tumour grows bigger before removal. The surgeons and researchers in Trondheim decided to investigate the outcome of a strategy where they removed the tumours while they were still small and not yet causing the patient incapacitating symptoms. They then compared the results to those from the conservative strategy.

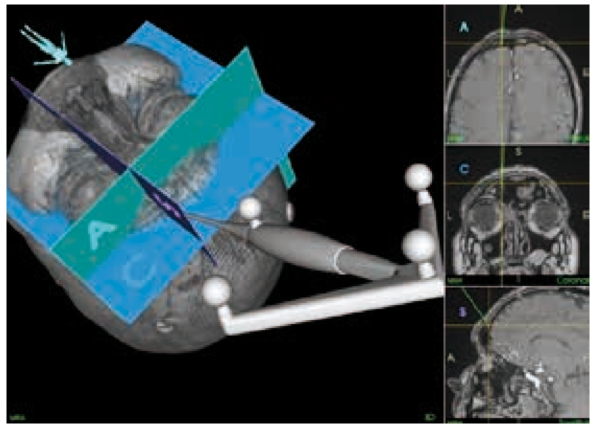
The results were surprisingly good for the group of patients who had early surgical removal of the tumour. The 5-year survival rate increased to 74% compared to a rate of 60% for patients following the conventional conservative treatment strategy. Also, the median survival increased from 5.9 years with conservative strategy to more than 14 years with the Trondheim strategy. The risk for adverse events due to surgery did not increase. For low-grade tumours one should therefore adopt the strategy, which has been implemented at St. Olavs Hospital for more than a decade.

Need for more research

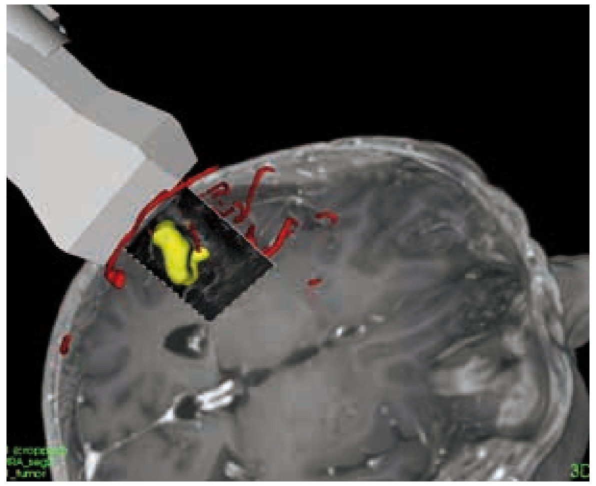
Does this mean that no further research is needed and that the method is now perfect? Far from it, if you ask Selbekk: "There are several challenges still to be met. One of them is the contrast of the ultrasound images. To address this we are developing a special kind of fluid to add to the cavity in the brain to improve the ultrasound images. It's a technical thing to do with the way sound travels in different materials. Sound travels through water without much attenuation, whilst brain tissue dampens sound much more. So we're making a type of fluid that is acoustically adjusted to get better images.

"Also, as for any tool or instrument, there is a need for education and training of neurosurgeons in how they should use ultrasound to improve their surgery."

After almost twenty years of using ultrasound assisted surgery Unsgård is certain of a few things: "This method is better for the patient in every way, and nothing is more important than that. Also, I hope politicians will come to the same understanding that we have. If you want research to become beneficial to people, and be commercialized as new technology or methods, it takes patience, time and dedication."



The MR images are made while the patient lies on his or her back, head tilted slightly backwards. During surgery, the patient may be belly down, head on the side – depending on the location of the tumour and chosen entry point.



The ultrasound probe has a navigation system that works almost like GPS.

PhDs

ASGEIR STORE JAKOLA, *Risks and benefits of brain tumour surgery – a balancing act*, 2013

TORMOD SELBEKK, *Ultrasound imaging in neurosurgery – delineation of tumours for resection control,* 2013

DANIEL HØYER IVERSEN, *Improved methods for navigated 3-D vascular ultrasound imaging*, 2014

MI•LAB FINAL REPORT

HOW MUCH of the brain is damaged?

Photo: Geir Mogen/NTNU.

Researchers at MI Lab, NTNU, have obtained new knowledge about traumatic brain injuries and helped industry develop a method to determine the extent of of the brain damage.

Imagine that you have fallen down from a ladder and suffered a mild concussion, or perhaps that you have severely injured your head in a car accident. Will this injury affect your life in the future? Do you need to re-educate yourself? And how can you prove the brain damage in a compensation case?

NeuroQuant is a software developed to calculate cerebral atrophy in Alzheimer patients. In collaboration between CorTechs Labs in the USA, the firm behind NeuroQuant and a research partner in MI lab, and researchers at NTNU expanded the programme to a new application, namely patients with traumatic brain injury.

Persons who have suffered traumatic brain injury, whether it is mild or serious, can experience different types of afflictions following the injury such as tiring more easily than previously and having problems with focusing. Despite the presence of such symptoms the brain damage is not always visible on MRIs, especially in the later phase after injury. This means that the doctors often are unable to identify the underlying cause of the problem. In fact, some types of brain damage can only be seen on an MRI for a short period of time after the damage has occurred.

One way of identifying brain injury is to compare the brain's structure of a person suffering from a brain injury to what is normal for a person that age, and to determine where the loss is located. In this manner it is a possible to obtain an objective measurement of the extent of the brain damage, even if there are no clearly visible areas of damage on the MRIs.

"Early MRI can immediately establish the exact type, extent and location of the brain damage in a patient who has hit his/her head or suffered an accident. This gives a foundation for providing the correct treatment and follow-up," says Professor Asta Håberg.

Proving the damage at an early stage after a head injury, and to obtain an objective measurement of the loss of brain tissue at a later stage, can also be important to ensure that the patient receives compensation in the event of a court case.

"We can perform accurate calculations of the brain volume and compare this to the standard for people of the same age. This way, we can replace educated guesses with objective measurements," Håberg concludes.

The research performed by Håberg and her colleagues also includes examining how the brain works after a head injury, not only how its volume and shape are affected.

"We have established that patients with traumatic brain injuries use their brains in a different way from persons without head injuries. They have to be more alert and activate their brain cells more to achieve the same results as those without brain injuries. The more serious the injury, the more the person in question has to use his or her brain.

Professor Asta Håberg

Photo: Geir Mogen/NTNU.

Where others can rely on automaticity, persons with moderate to serious head injuries always have to be more alert," Håberg explains.

This means that everyday activities, work and education become more laborious than before.

Researchers surprised by results

That the NeuroQuant software could be used to calculate the brain volume in patients with head injuries actually came as a surprise to Professor Håberg:

"When initiating the project, we were not entirely sure if the programme would be able to separate between damaged and healthy brain tissue," she now admits.

There is actually a significant difference between an older brain suffering from dementia and a young brain with traumatic brain injury-related damage.

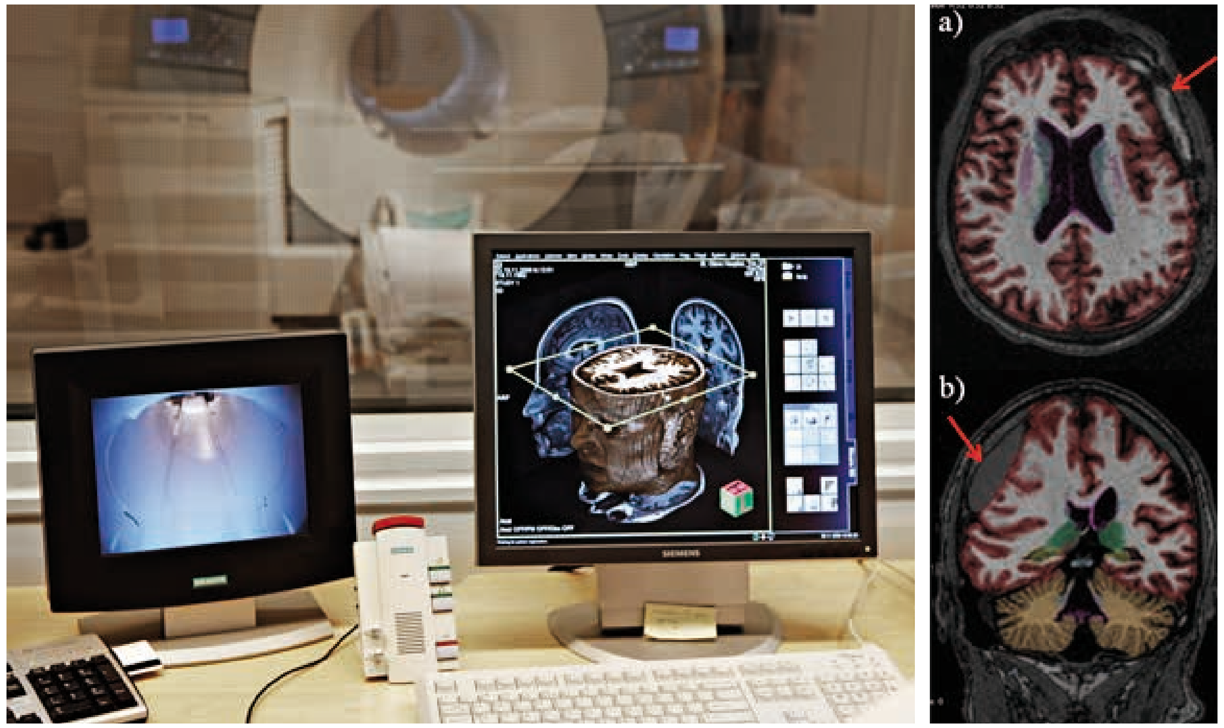
Fortunately, the research project produced great results. The collaboration with the NTNU researchers resulted in a new module in CorTechs Labs' programme. This module is now in use in hospitals around the world.

Calculating the brain size

NeuroQuant was originally developed to determine the volume of the hippocampus, the ventricles and other parts of the brain of Alzheimer's dementia patients. MRIs are uploaded to the computer programme, which calculates the volume and compares it to the standard volume for a person of the same age. Deviations in brain volume compared to the average for people of the same age give information about the risk and/or development of dementia.

The same method for measuring the volume of different brain structures also works for patients with traumatic brain damage.

If you hit your head hard enough, the brain will suffer different injuries, like brain contusion, bleeding or diffuse damages to areas in the central part of the brain. Bleedings can dislocate the healthy brain tissue, and contusion causes the brain tissue to die. These damages are visible on a regular MRI, and this type of damaged tissue or bleedings should not be part of the calculation of the different brain volumes. The NTNU researchers were the first to demonstrate that NeuroQuant can separate between bleedings and disintegrated tissue, allowing the programme to be used for calculating different brain volumes in patients with traumatic brain injuries.



NeuroQuant segmentation of two different TBI patients in acute postinjury phase depicting a) subdural hematoma b) epidural hematoma.
(Photo: Veronika Brezova)

Bjarte Snekvik and Alexander Olsen prepare for an fRMI examination. During an fMRI, the patient solves tasks inside the MRI scanner. This enables the researchers to see which parts of the brain are active when performing the task and how it differs between patients and control groups.

In their subsequent research, they have followed patients with head injuries for one year after the injury. This has provided the world's first data set of the changes in different brain structures across multiple time points over the course of one year in the same individual. Among other things, the researchers have used this data to uncover which early changes predict long-term functional outcome, and how different types of damage can cause different types of brain volume loss.

Until recently, they have focused on patients with moderate and severe injuries, but they have now started including patients with mild head injuries, like concussions.

"We are hoping to learn more about patients who have suffered a mild head injury and continue to experience long-term problems with for instance attention," Håberg explains.

This research project is part of a large EU project in which researchers and physicians at NTNU and St. Olavs Hospital are participants. The participating group is an interdisciplinary team of researchers from NTNU and MI Lab, and the MRI research group at St. Olavs Hospital, as well as physicians and researchers within neurosurgery and rehabilitation medicine at the hospital.

PhDs

VERONIKA BREZOVA, *Prospective MRI volumetry and diffusivity changes during the first year after traumatic brain injury: impact of injury related parameters, significance for outcome and methodological considerations*, 2014

TORUN GANGAUNE FINNANGER, *Life after Traumatic Brain Injury – Cognitive, Emotional and Behavioural Function after Moderate and Severe Traumatic Brain Injury*, 2014

KENT GØRAN MOEN, *Traumatic axonal injury in traumatic brain injury - Conventional and advanced MRI from early to chronic phase and relation to outcome*, 2014

ALEXANDER OLSEN, *Cognitive control function and moderate-to-severe traumatic brain injury - Functional and structural brain correlates*, 2014.

MI•LAB FINAL REPORT

5. IMPORTANCE FOR INDUSTRY AND SOCIETY

MI Lab was able to facilitate cost-efficient health care and improved patient outcome through innovations in medical imaging, and the innovations could also help the MI Lab industrial partners to improve their success in the international market.

GE Vingmed Ultrasound was the most active industrial partner in MI Lab, both through their R&D department co-localized with MI Lab in the integrated university hospital in Trondheim (St. Olavs University Hospital), and through their in-house R&D activities in Horten and Oslo. Historically, GE Vingmed Ultrasound has had a long and productive collaboration with NTNU. MI Lab was a further extension of this collaboration and has been a key instrument in expanding ultrasound into new markets. GE Vingmed's broad research focus is one of the pillars of its in-depth, technological competence and was an important factor in gaining status as Center of Excellence for development of 4D probe technology and software applications in GE's international ultrasound business.

GE Vingmed Ultrasound has identified some opportunities that would not have existed without MI Lab:

- Key product features for their advanced high-end cardiology product were developed as a result of the research collaboration with MI Lab.
- Continued idea generation in technology and medicine, an important motivation for both scientists and engineers.
- Clinical research during the development of the hand-held pocket-sized ultrasound system Vscan provided critical insight into user needs which were addressed already before product launch.
- The MI Lab research collaboration funnelled ideas for new product development and new applications for potential commercialization in the future.

The MI Lab industrial partners MediStim, Nordic NeuroLab, Sonowand, Aurotech Ultrasound and CorTechs Labs are small and medium-sized enterprises (SMEs) with a high level of competence in their R&D departments. Even though the resources they could put into the long-term research in MI Lab were limited, they benefited from and highly appreciated their participation in MI Lab. MI Lab was seen as an important trans-disciplinary platform for the development of methods and technology relevant to their products. And they appreciated that without MI Lab, participation in long-term research activities for future new products would be very difficult for companies of their size.

Some examples of important benefits for the SMEs are:

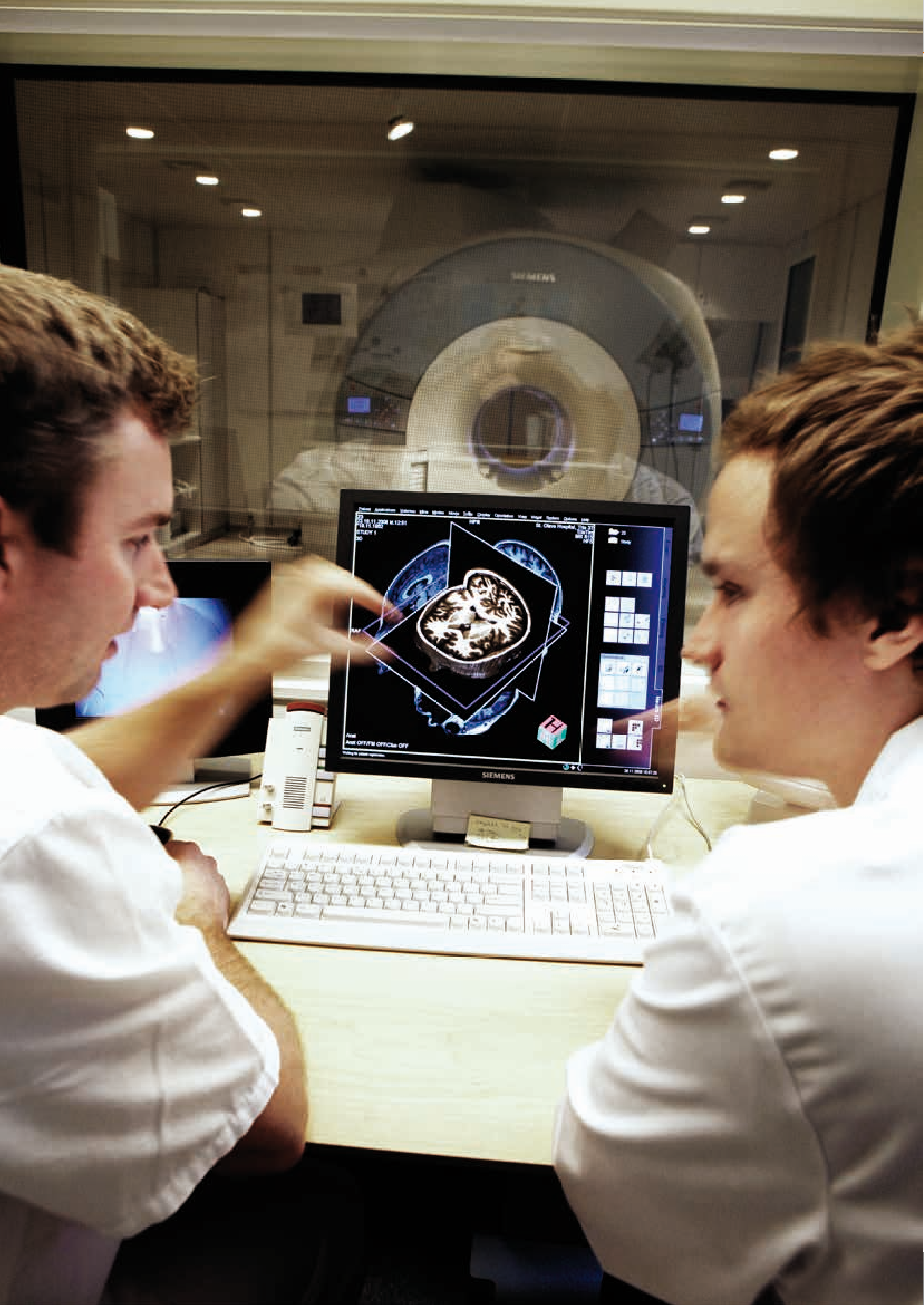
- MediStim obtained, based on scientific evidence from clinical studies, an official recommendation for their VeriQ system from the British National Institute for Health and Clinical Excellence. Cited from the recommendation: "The case for adopting the VeriQ system in the National Health Services for assessing graft flow during coronary artery bypass graft surgery is supported by the evidence".
- Nordic NeuroLab benefited from research into new methods for tissue mapping using advanced diffusion imaging (restriction spectrum imaging). The research was performed by one of the MI Lab PhD candidates during her research stay with the MI Lab guest professors, Anders Dale, at the University of San Diego, California, USA.
- CorTechs Labs obtained, through MI Lab research, clinical evidence that their Neuroquant software can be used to map traumatic brain injury (TBI) pathology, and this was implemented as the new Triage brain atrophy report in Neuroquant.

The four ultrasound companies in MI Lab all wanted to continue the collaboration, and they were part of the successful application for a new Centre for Research-Based Innovation (SFI) CIUS (Centre for Innovative Ultrasound Solutions).

MI Lab research and innovation also benefited society through applications in the health care sector through new and/or improved methods for patient diagnosis, treatment and follow-up. St. Olavs University Hospital was an active partner in MI Lab, and a broad range of hospital physicians were involved in the MI Lab projects. For St. Olavs University Hospital many of the new methods could be applied directly to everyday routines without passing through product development by the industrial partners. Furthermore, the three-way collaboration between university, industry and hospital helped raise the quality of medical technology research and innovation in the hospital, and also produced important feed-back to the industry about potential improvements to their products, and was the source of creative ideas about completely new applications of medical imaging technology that could improve patient handling and outcome.

An important challenge worldwide is to obtain sustainable health care and welfare systems, and MI Lab had a strong focus on innovation that could combine the facilitation of cost-efficient health care and improved patient outcome. Medical imaging could be central to meeting the challenges of sustainable health care through:

- High quality medical imaging products and applications for non-expert users at the initial point of care.
- Less complications and more rapid patient rehabilitation with image-guided, minimally invasive surgery.
- More rapid and more precise choice of efficient treatment through decision-making based on advanced medical imaging.



6. TRAINING OF RESEARCHERS

MI Lab decided to use most of the cash budget to hire PhD students and post docs, and a total of 32 PhD students and 19 post docs were fully or partly funded by the centre. MI Lab also acted as a driving force for the medical imaging research environment in Trondheim, and a further 40 completed PhDs and 16 post carried out their research in connection to MI Lab.

This focus on researcher training was highly appreciated by the partners and was also supported by the MI Lab Scientific Advisory Board. Cited from their report:

"The injection of these funds into graduate training creates a powerful stimulus for the project to produce a generation of highly trained personnel that will help sustain NTNU and its local industrial partners. The students we met, and whose publications we have read, impressed us with their high academic and intellectual level, their commitment and their maturity. We see this as a very positive aspect of the project."

To further improve the quality of the PhD training, MI Lab leader Olav Haraldseth initiated, and is the current leader of, the Norwegian Research School in Medical Imaging (MedIm - www.ntnu.no/medicalimaging). The Research Council of Norway had their first call for post graduate researcher training programmes [forskerskoler] in 2008, and the Norwegian Research School in Medical Imaging was one of the five appointed. It is hosted by NTNU and is a collaboration with the universities in Oslo, Bergen and Tromsø. It is open for all Norwegian PhD students in the area of medical imaging (including MRI, ultrasound, PET, image guided surgery, advanced light microscopy and bionanotechnology). The main aim is to improve the quality of medical imaging research in Norway, and MedIm has been successful through improving national collaboration, transdisciplinary research, the quality of PhD training, and the recruitment of the best students.

MI Lab proved to be an important recruitment base for highly skilled personnel to Norwegian industrial R&D, health care and academia. The following table shows the present employment of the 32 PhD students funded by MI Lab:

Present employment of PhD-candidates (number)							
By MI Lab industrial partner	By other industrial companies	By hospital	By university	By research institute	Outside Norway	Other	Total
2	5	12	7	3	2	1	32

MI•LAB FINAL REPORT

PRESENTATION OF FOUR PHD STUDENTS

INGVILD KINN EKROLL

I chose to apply for a PhD fellowship at MI Lab because it gave a unique opportunity to carry out research in medical imaging. With a master's degree in biophysics and medical technology I wanted to work in this field. By choosing ultrasound imaging of blood flow as the theme for my PhD, I also got the opportunity to work in a world leading research environment. I found it rewarding to work at the centre, not least because it has been focusing on collaboration with hospital physicians and testing new imaging techniques in the clinic. One of my scientific publications (Ekroll et al. *Combined Vector Velocity and Spectral Doppler Imaging for Improved Imaging of Complex Blood Flow in the Carotid Arteries*. Ultrasound in medicine & biology 2014) describes the results of such collaboration. A brand new imaging method was successfully tested on a relevant group of patients at the outpatient clinic of Vascular Surgery at St. Olavs Hospital. Presently I continue my research in the same research group in a post doc project funded by the Central Norway Regional Health Authority [Helse Midt-Norge]. The project's main focus is the ultrasound imaging of blood flow and tissue movement for improved diagnosis of disease in the carotid arteries.

SIRI ANN NYRNES

MI Lab was a central contributor to getting my research started, developing ideas which extended the project, and my being able to continue with research after my PhD.

I was working as a consultant in paediatric cardiology when I was asked to try out a new ultrasound method for the visualization of blood flow, Blood Flow Imaging (BFI), in congenital heart disease. I was accepted for a tailored part time research position as a PhD candidate combined with clinical work at the paediatric department at St. Olavs Hospital, and this was of vital importance for the realization of the project. The transdisciplinary teamwork in MI Lab was inspiring. During my PhD the BFI technique was taken from its early stages and developed further in an interactive collaboration with engineers and the industrial partner GE Vingmed Ultrasound. Through clinical feasibility studies, the method has been further improved and is now at a stage where it is ready for larger studies. When I finished my PhD, MI Lab offered me a 20% post doc position to be able to continue this work in parallel with clinical work at the hospital. I have now prepared a protocol for an international collaboration project, obtained the funding for this, and in September this extension of the project will be started at the SickKids Hospital in Toronto, Canada. This collaboration makes it possible to include a sufficient number of patients with different types of congenital heart disease to, hopefully, be able to find scientific evidence of the benefit to the patients and establish the method as new clinical practice.

ALEXANDER OLSEN

As an authorized clinical psychologist, I was attracted to MI Lab because of my interest in brain research using MRI, the transdisciplinary profile, and the focus on innovation and collaboration with the clinic. I found it a rewarding place to work. My PhD project focused on the use of different MRI methods in patients with traumatic brain injuries. In my daily work, and through the "MI Lab Day" meetings, I was exposed to and became familiar with a number of professionals and specialists with very different backgrounds from myself. In retrospect, I see that this has been very useful, both in terms of specific skills that I have acquired from professionals (eg. mathematicians, physicists, engineers, physicians) and not least through the development of research ideas and solutions that have come as a result of cooperation and being part of a transdisciplinary network. My transdisciplinary expertise and experience has been seen as useful and attractive by my current employers. Today I have a combined position as associate professor at the Institute of Psychology, NTNU, and neuropsychologist at the Department of Physical Medicine and Rehabilitation, St. Olavs Hospital. I am also employed as project scientist at UCLA, USA, to follow up on a research project there. My goal for the future is to continue to develop my research in the interface between clinical neuroscience and medical imaging.

OLE CHRISTIAN MJØLSTAD

In 2009 I had almost finished my cardiology education and was very determined to obtain a PhD. MI Lab was a tempting option as a transdisciplinary academic platform in general, and for medical imaging in particular. MI Lab offered good supervisors with different backgrounds, and a project within the clinical use of hand held pocket-sized ultrasound was very exciting and spot on for what I considered to be clinically useful research. I got the opportunity to carry out research in a 50% position, which was important to me at the time as I had a wish to continue with ordinary clinical work as well. Even though I only carried out research part-time I was able to finish my PhD in 4 years with the thesis: "Pocket-size ultrasound, a new diagnostic tool in clinical practice." I received good supervision and back-up from MI Lab. I had a project-economy sufficient to carry out the patient studies efficiently and participate at international research conferences and meetings. Research was considered my main task – and apart from dissemination to the public of the exciting potential of pocket-size ultrasound, I had few other commitments. After completing the PhD I have worked full time as a cardiologist at St. Olavs Hospital, and combine this with a 20% position at NTNU as a researcher with an emphasis on working with clinical application of pocket-size ultrasound.

7. INTERNATIONAL CO-OPERATION

The MI Lab partners and involved research groups have extensive international networks, and in the MI Lab publication list **25% of the full scientific papers have co-author(s) from institutions outside of Norway**.

One of MI Lab's strategies for strengthening international collaboration was to attach foreign professors and researchers in 10-20% positions as international guest professors and guest researchers for shorter or longer periods. The most important international collaborations were with the following:

- Guest researcher Jan D'hooge, Department of Cardiovascular Imaging and Dynamics, Catholic University Leuven, Belgium
- Guest researcher Jean-Francois Gelly, Parallel Design SA, Sofia Antipolis, France
- Guest professor Arend Heerschap, Department of Radiology, Radeboud University, Nijmegen, Netherlands
- Guest professor Anders M. Dale, Multimodal Imaging Laboratory, University of California San Diego, USA
- Guest professor Henrik Larsson, Unit for Functional Image Diagnostics at Glostrup University Hospital, Copenhagen, Denmark

MI Lab also had a wish to improve the collaboration with the ultrasound research environment in Oslo (both cardiology and technology), and hired two guest professors:

- Svend Aakhus, consultant in cardiology, Oslo University Hospital (Rikshospitalet)
- Sverre Holm, Centre for Imaging at the Department of Informatics, University of Oslo

These guest professors and guest researchers were chosen because they had a level of competence and research experience that was of benefit to MI Lab, and, at the same time, they looked upon MI Lab as an important opportunity for improving their own research through active participation in the research environment in Trondheim.

MI•LAB FINAL REPORT

8. FUTURE PROSPECTS

All the MI Lab affiliated research groups have been able to attract new external funding from several sources, and the medical imaging research and innovation activity in Trondheim is growing fast even though the MI Lab funding ceases.

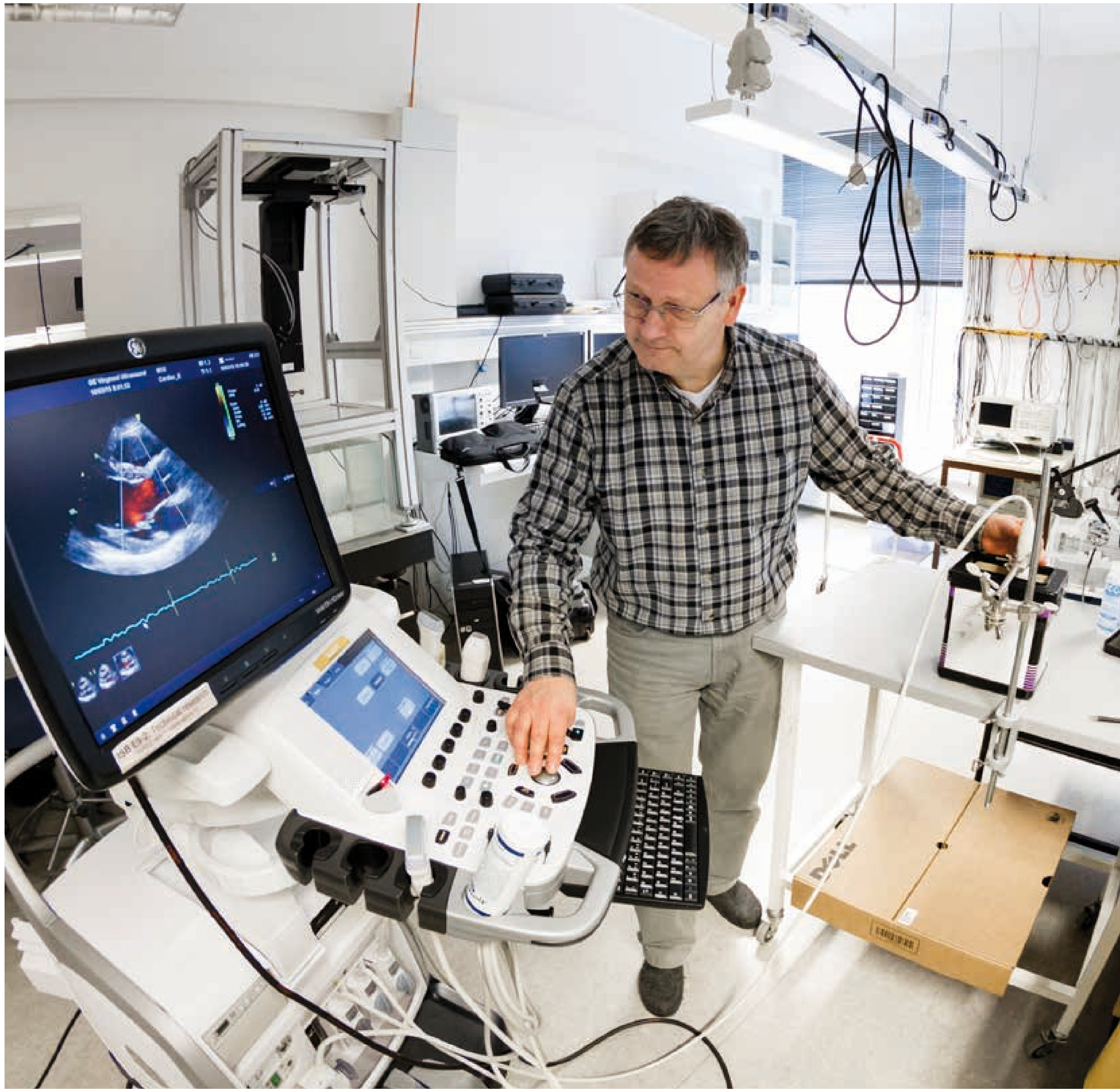
Most important for the ultrasound research and innovation, is the new Centre for Research-based Innovation CIUS (Centre for Innovative Ultrasound Solutions) appointed by the Research Council of Norway in 2014. The CIUS concept is to join forces and explore synergies between Norwegian health care, maritime and oil & gas industrial sectors that all will benefit from basic ultrasound technology innovation in a wide range of products and applications. CIUS, with NTNU as the host institution, will improve national research collaboration with the University of Oslo, the University College of Buskerud and Vestfold and SINTEF as research partners.

There are a total of 11 industrial partners. The ultrasound industrial partners in MI Lab are partners in CIUS, and the main new partners in the maritime and oil & gas sectors are Statoil and Kongsberg Maritime. St. Olavs Hospital is the main public partner. And in order to continue the research with handheld pocket-sized ultrasound Levanger Hospital and the municipalities of Levanger and Verdal are partners. CIUS has a total cash budget of approx. NOK 150 million (Euro 16 million) for the 8-years period, and the in-kind financial contributions from the partners amount to approx. NOK 285 million (Euro 31 million).

Important for the image-guided surgery and therapy activity is the Research Council of Norway appointed national infrastructure NorMIT (Norwegian Centre for Minimally Invasive Image Guided Therapy and Medical Technologies). The host institution is St. Olavs Hospital, and NTNU, Oslo University Hospital, the University of Oslo and SINTEF are partners. NorMIT has a total investment budget of NOK 217 million (Euro 24 million), of which NOK 54 million (Euro 6 million) is funded by the Research Council of Norway. NorMIT is an excellent arena for further research and innovation within a wide range of image-guided surgery and therapy applications.

Important for MRI research and innovation is the establishment of a unique co-localization of the first clinical hybrid PET-MR system and the first clinical 7 Tesla MRI system in Norway. The latter is part of the national infrastructure NORBRAIN headed by the Nobel prize winner professor Edvard Moser. NORBRAIN will focus on research in the fields of normal brain function and functional and pathological changes in brain diseases. One of the main goals is to obtain new knowledge about dementia in neurodegenerative diseases (Alzheimer's and others) and use the knowledge to find new and innovative therapeutic targets. However, the advanced technology in the clinical PET-MR and 7 Tesla MRI systems will enable new and unprecedented research and innovation opportunities for several organ systems and patient groups.

MI Lab was also instrumental in the establishment of the National Researcher School in Medical Imaging (MedIm) described on page 27, and the innovation cluster Nansen Neuroscience Network (NNN). MI Lab was one of the two founding partners for the Nansen Neuroscience Network, which is a knowledge network focusing on innovation in neurosciences by bringing together industry and academia through virtual platforms, seminars and meetings. At present it has 41 members from academia, health care and industry.



MI•LAB FINAL REPORT

9. CONCLUSION

MI Lab was successful in many areas, and we believe that the main success factors were the strong focus on transdisciplinarity, researcher training, the culture for innovation, and the role for medical imaging in finding cost-efficient solutions that can help create sustainable health care systems. All these factors were also important for the industrial partners in order to develop products that can be successful in the international market.

Transdisciplinarity is a must in order to achieve research and innovation at a top international level both in medicine in general, and in medical imaging in particular. And to achieve good transdisciplinarity it is not sufficient to have occasional project meetings. It is necessary that each sub-project is a close collaboration over time between PhD students, post docs and senior researchers/supervisors from the different master backgrounds and disciplines, and that the involved researchers, as far as possible, belong to the same physical environment. Most of the people involved in MI Lab in Trondheim had their offices in the same building at St. Olavs University Hospital, and this building also houses a GE Vingmed Ultrasound R&D department.

Many of the involved medical doctors combined their PhD work with clinical positions at the hospitals, typically on a 50-50 basis, and several hospital physicians were funded by MI Lab in 20% post doc positions. The MI Lab researchers enjoyed working in such a transdisciplinary environment, and many of the PhD candidates wanted to continue their research in the same environment after completing their PhDs. In this context MI Lab also benefited from the strategies of the Faculty of Medicine at NTNU and at St. Olavs University Hospital. The Faculty of Medicine has a long tradition for combining technology, natural sciences and medicine in their activities. There are many professors from disciplines other than medicine, and PhD students from other master backgrounds are actively recruited to the transdisciplinary research projects and are allowed to join the faculty's PhD programmes. Furthermore, the new St. Olavs University Hospital is becoming a fully integrated university hospital with all the NTNU Faculty of Medicine offices and laboratories localized in the hospital buildings, and with a mutual strategy for integration of all research activities and research infrastructures.

MI Lab also focused on building a culture for innovation. During the first years of MI Lab, all new PhD candidates and post docs had separate meetings with the NTNU Technology Transfer Office (TTO) to discuss the innovation potential of their projects. The basic message was for the PhD candidates and post docs to be self-confident in creating their own ideas, and to lower the threshold for disclosing the ideas as inventions and discuss the potential for patents. This was also strengthened by a personal economic remuneration of NOK 50,000 to the inventors of all new ideas when patent processes were started.

Finally, we want to thank the Research Council of Norway for the Centres for Research-based Innovation (SFI) scheme. For our research environment it was highly beneficial to be further pushed into a working modus of open innovation and long-term industrial research.

Tables

Results - Key figures

Data as of 1. September 2015

	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Scientific publications (peer reviewed)	16	23	22	36	37	47	43	38	33	295
Dissemination for users	0	45	55	58	62	119	122	102	53	616
Dissemination for the general public	0	7	5	3	8	8	8	8	3	50
Number of new and/or improved methods and products	0	0	4	6	8	10	8	7	2	45
PhD-degrees completed	0	0	0	2	3	1	5	9	2	22
Master degrees										25*

**MI Lab focused on researcher training at PhD and post doc level, and few master's students were directly involved in the MI Lab research activities, one reason being problems for regulation of Intellectual Property Rights as the master's students are not employed by NTNU and thus have a personal ownership to their inventions. It is estimated that a total of approx. 25 master students were involved in MI Lab related research.*

MI Lab had a total of 11 inventions that led to patent processes:

Patent processes – title of invention
Deformable models for real-time segmentation of cardiac structures in volumetric data.
Automatic Alignment of Image Views in 3D Echocardiograms From Fitted Deformable Models.
Sparse acquisition of tissue Doppler imaging based on image segmentation.
Semiquantitative grading of valvular regurgitation using pulsed wave Doppler and parallel receive beams.
Adaptive Spectral-Doppler for improved Velocity Measurements and retrospective PW-Doppler in Medical Ultrasound Imaging.
Quantitative grading of valvular regurgitation using high pulse repetition frequency 3D Doppler with velocity matched spectrum.
Model-based correction of angle-dependencies and estimation of volume flow in navigated 3D flow imaging (during neurosurgical interventions).
A new scan pattern based on multiple simultaneous transmissions for use in three dimensional ultrasound imaging at high framerate, high resolution.
Multi-angle Doppler imaging for automated quantitative analysis.
A new design for medical ultrasound transducers for very high frame rate ultrasound imaging.
Reflector reconstruction in Ultrasound images by Image Source.

Appendix 1

Statement of accounts for the complete period of centre financing (in MNOK).

As of 1. September 2015

Funding

		Host	Industrial partners								Public partners		Research partner	
Research Tasks (RTs) and other activities	RCN	NTNU	GEVU	Medi-stim	NNL	Cor-Techs	Odetect	Sono-wand	ASD	Aurotech	St. Olavs Hospital	HMN	SINTEF	**Total**
RT 1	26 901	6 680	26 046	0	0	0	0	0	133	422	0	450	1 198	**61 831**
RT 2	15 103	3 338	34 660	0	0	0	0	0	0	0	2 262	5 850	0	**61 213**
RT 3	10 319	3 535	0	4 507	0	0	0	252	0	0	270	3 000	9 983	**31 866**
RT 4	16 894	12 562	0	0	2 777	1 317	566	0	0	0	7 443	5 700	602	**47 861**
Equipment	0	0	0	0	0	0	0	0	0	0	0	0	105	**105**
Management	6 856	9 939	0	0	0	0	0	0	0	0	0	0	0	**16 796**
Sum	**76 074**	**36 055**	**60 706**	**4 507**	**2 777**	**1 317**	**566**	**252**	**133**	**422**	**9 975**	**15 000**	**11 889**	**219 671**

Costs

		Host	Industrial partners								Public partners		Research partner	
Research Tasks (RTs) and other activities	RCN	NTNU	GEVU	Medi-stim	NNL	Cor-Techs	Odetect	Sono-wand	ASD	Aurotech	St. Olavs Hospital	HMN	SINTEF	**Total**
RT 1	0	36 949	23 218	0	0	0	0	0	133	422	0	0	1 198	**61 920**
RT 2	0	27 557	31 195	0	0	0	0	0	0	0	2 182	189	0	**61 123**
RT 3	0	18 508	0	2 854	0	0	0	252	0	0	270	0	9 983	**31 866**
RT 4	0	35 045	0	0	2 777	1 317	566	0	0	0	7 430	124	602	**47 861**
Equipment	0	0	0	0	0	0	0	0	0	0	0	0	105	**105**
Management	0	16 796	0	0	0	0	0	0	0	0	0	0	0	**16 796**
Sum	**0**	**134 854**	**54 413**	**2 854**	**2 777**	**1 317**	**566**	**252**	**133**	**422**	**9 882**	**313**	**11 888**	**219 671**

RCN: Research Council of Norway
GEVU: GE Vingmed Ultrasound
NNL: Nordic NeuroLab
ASD: Arctic Silicon Devices
HMN: Helse Midt-Norge

Appendix 2

List of postdocs and candidates for PhD degrees during the full period of MI Lab.

Postdoctoral researchers with financial support from the MI Lab budget

Name	M/F	Nationality	Scientific area	Master's background	Scientific topic	Main contact
Brage Høyem Amundsen	M	Norway	Ultrasound	Medicine	Cardiac ultrasound	Asbjørn Støylen
Tore Bjåstad	M	Norway	Ultrasound	Tele-communications	Ultrasound image improvement	Hans Torp
Morten Bruvold	M	Norway	MR	Molecular Biology	Manganese enhanced MR Imaging	Olav Haraldseth
Håvard Dalen	M	Norway	Ultrasound	Medicine	Pocket-sized hand-held ultrasound	Sigmund Frigstad
Ole Christian Eidheim	M	Norway	MRI	Computer science	Functional MR Imaging	Olav Haraldseth
Live Eikenes	F	Norway	MRI	Physics	Functional MR Imaging	Asta Håberg
Bjørn Olav Haugen	M	Norway	Ultrasound	Medicine	Pocket-size hand held ultrasound	Sigmund Frigstad
Torbjørn Hergum	M	Norway	Ultrasound	Physics	Cardiac ultrasound	Hans Torp
Charlotte Bjørk Ingul	F	Sweden	Ultrasound	Medicine	Cardiac ultrasound	Asbjørn Støylen
Gabriel Kiss	M	Rumania	Ultrasound	Computer science	Cardiac ultrasound	Hans Torp
Alfonso Morales	M	Spain	Ultrasound	Electrical engineering	Ultrasound image improvement	Hans Torp
Håvard Nordgaard	M	Norway	Image guided surgery	Medicine	Ultrasound guidance in Thoracic surgery	Dag Ole Nordhaug
Siri-Ann Nyrnes	F	Norway	Ultrasound	Medicine	Cardiac ultrasound in new-borns	Lasse Løvstakken
Helen Palmer	F	UK	MRI	Physiology	Functional MR Imaging	Asta Håberg
Ingerid Reinertsen	F	Norway	Image guided surgery	Physics	Ultrasound guidance in Neurosurgery	Geirmund Unsgård
Ole Solheim	M	Norway	Ultrasound	Medicine	Ultrasound guidance in Neurosurgery	Geirmund Unsgård
Niels M. van Strien	M	Netherlands	MRI	Psychology	Functional MR Imaging	Olav Haraldseth
Marco Voormolen	M	Netherlands	Ultrasound	Biomedical engineering	Ultrasound image improvement	Hans Torp
Svein Arne Aase	M	Norway	Ultrasound	Computer science	Ultrasound image improvement	Hans Torp

Postdoctoral researchers working in connection to MI Lab projects with financial support from other sources

Funding abbreviations:
HMN = [Samarbeidsorganet Helse Midt-Norge/NTNU]
NCS= Norwegian Cancer Society
RCN = Research Council of Norway

Name	M/F	Nationality	Source of funding	Scientific area	Master's background	Scientific topic	Main contact
Reidar Brekken	M	Norway		Image guided surgery		Ultrasound guidance abdominal surgery	Toril Hernes
Maria Dung Cao	F	Norway	HMN	MRI	Molecular medicine	MR Metabolomics	Tone Bathen
Michael Chappell	M	New Zealand	RCN	MRI	Technology	Functional MR Imaging	Asta Håberg
Guro Giskødegård	F	Norway	HMN	MRI	Mathematics	MR Metabolomics	Tone Bathen
Rune Hansen	M	Norway	HMN	Ultrasound	Engineering	SURF Technology	Toril Hernes
Debbie Hill	F	UK	HMN	MRI	Molecular Biology	Preclinical MR Imaging	Tone Bathen
Else Marie Huuse	F	Norway	NTNU	MRI	Physics	Preclinical MR Imaging	Olav Haraldseth
Hanne Lehn	F	Norway	NTNU	MRI	Psychology	Functional MR Imaging	Asta Håberg
Siver A Mostue	M	Norway	NCS	MRI	Pharmacology	MR in cancer	Tone Bathen
Tina Pavlin	F	Slovenia	NTNU	MRI	Physics	MR Technology	Olav Haraldseth
Ioanna Sandvig	F	Greece	HMN	MRI	Molecular Biology	MR guidance of regenerative medicine	Olav Haraldseth
Kristin Selnæs	F	Norway	HMN	MRI	Physics	MR in cancer	Tone Bathen
Beathe Sitter	F	Norway	NTNU	MRI	Chemistry	MR metabolomics	Tone Bathen
May B.Tessem	F	Norway	NTNU	MRI	Chemistry	MR in cancer	Tone Bathen
Marte Thuen	F	Norway	RCN	MRI	Physics	Manganese enhanced MR Imaging	Olav Haraldseth
Marius Widerøe	M	Norway	NTNU	MRI	Medicine	Preclinical MR Imaging in pediatrics	Olav Haraldseth
Andreas Aaslund	M	Sweden	RCN	Ultrasound	Biomedical engineering	Ultrasound guided drug delivery	Olav Haraldseth

PhD candidates who have completed with financial support from the MI Lab budget

Name	M/F	Nationality	Scientific area	Master's background	Thesis title	Main thesis advisor
Garrett Newton Andersen	M	Norway	Ultrasound	Medicine	Point-of-care pocket-size ultrasonography - bringing the diagnosis back to the bedside.	Bjørn Olav Haugen
Jørgen Avdal	M	Norway	MRI & Ultrasound	Mathematics	Model-Based Evaluation of Blood Estimation Techniques	Hans Torp
Veronika Brezova	F	Czech Republic	MRI	Medicine	Prospective MRI volumetry and diffusivity changes during the first year after traumatic brain injury: impact of injury related parameters, significance for outcome and methodological considerations.	Asta Håberg
Bastien Denarie	M	France	Ultrasound	Medical Technology	Real-time 3-D echocardiography: challenges of parallel transmission and acquisition.	Hans Torp & Tore Bjaastad
Engin Dikici	F	Turkey	Ultrasound	Computer science	Ultrasound cardiac modelling, segmentation and tracking.	Hans Torp & Fredrik Orderud
Ingvild Kinn Ekroll	F	Norway	Ultrasound	Physics	Ultrasound imaging of blood flow based on high frame rate acquisition and adaptive signal processing.	Lasse Løvstakken
Solveig Fadnes	F	Norway	Ultrasound	Physics	Two-Dimensional blood velocity estimation for intracardiac flow assessment.	Lasse Løvstakken
Tonje Dorowen Fredriksen	M	Norway	Ultrasound	Physics	Quantitative Doppler Methods in Cardiovascular Imaging.	Hans Torp
Benjamin J. C. Garzon	M	Spain	MR	Mathematics	Clinical applications of multimodal magnetic resonance imaging.	Asta Håberg
Sjoerd Hak	M	Netherlands	MR	Molecular Biology	Optimization of oil-in-water nanoemulsions for tumor targeting and molecular dynamic contrast enhanced MRI	Olav Haraldseth
Tuva Roaldsdatter Hope	F	Norway	MR	Physics	Probing tissue microstructure in tumors and surrounding brain: Diffusion weighted MRI and beyond.	Atle Bjørnerud
Daniel Høyer Iversen	M	Norway	Ultrasound	Mathematics	Improved methods for navigated 3-D vascular ultrasound imaging.	Lasse Løvstakken
Asgeir Jakola	M	Norway	Ultrasound	Medicine	Risk and benefits of brain tumor surgery – a balancing act.	Geirmund Unsgård
Halvard Kaupang	M	Norway	Ultrasound	Physics	Models and methods for investigation of reverberations in nonlinear ultrasound imaging.	Bjørn Angelsen
Ole Christian Mjølstad	M	Norway	Ultrasound	Medicine	Pocket-size ultrasound, a new diagnostic tool in clinical practice.	Bjørn Olav Haugen
Håvard Nordgaard	M	Norway	Ultrasound	Medicine	Tranist-time flowmetry and wall shear stress analysis of coronary artery bypass grafts – A clinical and experimental study.	Rune Haaverstad
Siri Ann Nyrnes	F	Norway	Ultrasound	Medicine	New ultrasound flow modalities for evaluation of congenital heart defects.	Bjørn Olav Haugen
Alexander Olsen	M	Norway	MR	Psychology	Cognitive control function and moderate-to-severe traumatic brain injury - Functional and structural brain correlates.	Asta Håberg
Fredrik Orderud	M	Norway	Ultrasound	Computer science	Real-time segmentation of 3D echocardiograms using a state estimation approach with deformable models.	Bjørn Olstad
Ioanna Sandvig	F	Norway	MR	Molecular Biology	The role of olfactory ensheathing cells, MRI and biomaterials in transplant-mediated CNS repair.	Olav Haraldseth
Anders Thorstensen	M	Norway	Ultrasound	Medicine	2D and 3D echocardiography during inotropic alterations and after recent myocardial infarct.	Asbjørn Støylen
Jon Petter Åsen	M	Norway	Ultrasound	Computer science	Accelerating adaptive ultrasound imaging algorithms by means of general-purpose computing on graphics processing units.	Sverre Holm

PhD degrees working in connection to MI Lab projects with financial support from other sources

Funding abbreviations: HMN = [Samarbeidsorganet Helse Midt-Norge/NTNU] NCS= Norwegian Cancer Society RCN = Research Council of Norway

Name	M/F	Nationality	Funding source	Scientific area	Master's background	Thesis title	Main thesis advisor
Brage Høyem Amundsen	M	Norway		Ultrasound	Medicine	Myocardial function quantified by speckle tracking and tissue Doppler echocardiography.	Stig Slørdahl
Erik Magnus Berntsen	M	Norway	NTNU	MRI	Medicine	Preoperative planning and functional neuronavigation – with functional MRI and diffusion tensor tractography in patients with brain lesions	Olav Haraldseth
Helena Bertilsson	F	Sweden		MRI	Medicine	Prostate cancer – Translational research. Optimizing tissue sampling suitable for histopathologic, transcriptomic and metabolic profiling.	Anders Angelsen
Tore Bjåstad	M	Norway		Ultrasound	Tele-communications	High frame rate ultrasound imaging using parallell beamforming.	Hans Torp
Morten Bruvold	M	Norway		MRII	Molecular Biology	Manganese and water in cardiac magnetic resonance imaging.	Per Jynge
Maria Dung Cao	F	Norway	RCN	MRI	Molecular Medicine	MR metabolic characterization of locally advanced breast cancer – treatment effects and prognosis.	Ingrid Gribbestad
Jonas Crosby	M	Norway	RCN	Ultrasound	Cybernetics	Ultrasound-based quantification of myocardial deformation and rotation.	Hans Torp
Håvard Dalen	M	Norway	NTNU	Ultrasound	Medicine	Echocardiographic indices of cardiac function – Normal values and association with risk factors in a population free from cardio-vascular disease, hypertension and diabetes.	Asbjørn Støylen
Morteza Esmaeili	M	Iran	NTNU	MRI	Electrical Engineering	Development and application of phosphorous. MR techniques for diagnostic, prognostic, and therapeutic assessment of cancer.	Tone Bathen
Hallvard Røe Evensmoen	M	Norway	NTNU	MRI	Neuroscience	A functional segregation along the hippocampal anterior-posterior axis.	Asta Håberg
Guro Fanneløb Giskeødegård	F	Norway	RCN	MRI	Molecular Medicine	Identification and charcterization of prognostic factors in breast cancer using MR metabolomics.	Tone Bathen
Sjur Urdson Gjerald	M	Norway		Ultrasound	Technology	A fast ultrasound simulator.	
Maria Tunset Grinde	F	Norway	HMN	MRI	Physics	Characterization of breast cancer using MR metabolomics and gene expression analysis.	Ingrid Gribbestad
Thomas Moe Halvorsrød	M	Norway		Ultrasound	Electronics	On Low Power, Analog Modules for Medical Ultrasound Imaging Systems.	Trond Ytterdal

Name	M/F	Nationality	Funding source	Scientific area	Master's background	Thesis title	Main thesis advisor
Marianne Gjervik Heldahl	F	Norway	Several sources	MRI	Physics	Evaluation of neoadjuvant chemotherapy in locally advanced breast cancer based on MR methodology.	Tone Bathen
Torbjørn Hergum	M	Norway		Ultrasound	Physics	3D ultrasound for quantitative echocardiography.	Hans Torp
Khalid Shaker Ibrahim	M	India		Image guided surgery	Medicine	Intraoperative ultrasound assessment in coronary artery bypass surgery – with special reference to coronary anastomoses and the ascending aorta.	Rune Haaverstad
Frode Manstad Hulaas	M	Norway	RCN	Image guided surgery	Medicine	Image guided endovascular procedures	Hans Olav Myhre
Line Rørstad Jensen	F	Norway		MRI	Physics	Evaluation of treatment effects in cancer by MR imaging and spectroscopy.	Ingrid Gribbestad
Roar Johansen	M	Norway	HMN	MRI	Medicine	MR techniques in evaluation of breast cancer patients with poor prognosis.	Steinar Lundgren
Grete Kjelvik	F	Norway	HMN	MRI	Neuroscience	Human odor identification studies in healthy individuals, mild cognitive impairment and Alzheimer's disease	Asta Håberg
Hanne Lehn	F	Norway	NTNU	MRI	Psychology	Memory functions of the human medial temporal lobe studied with fMRI.	Asta Håberg
Siver Andreas Moestue	M	Norway	RCN	MRI	Pharmacology	Molecular and functional characterization of breast cancer through a combination of MR imaging, transcriptomics and metabolomics.	Ingrid Gribbestad
Tora Sund Morken	F	Norway	HMN	MRI	Medicine	Brain development and metabolism after hypoxia-ischemia and varying oxygen levels in neonatal rat studied with 13C-MRS and MRI.	Ann-Mari Brubakk
Sven Peter Näsholm	M	Sweden		Ultrasound	Technology	Ultrasound beams for enhanced image quality.	Bjørn Angelsen
Øystein Olsen	M	Norway	HiST	MRI	Physics	Analysis of manganese enhanced MRI of the normal and injured rat central nervous system.	Olav Haraldseth
Lene Anette Rustad	F	Norway	NTNU	Ultrasound	Medicine	Cardiac function at rest and during exercise in patients with healed myocardial infarction and in heart transplant recipients – Effects of high-intensity interval exercise program.	Brage Høyem Amundsen
Ola Morten Rygh	M	Norway		Image guided surgery	Medicine	3D ultrasound based neuronavigation in neurosurgery – A clinical evaluation.	Geirmund Unsgård
Tormod Selbekk	M	Norway		Image guided surgery	Technology	Ultrasound imaging in neurosurgery.	
Kirsten M. Selnæs	F	Norway	RCN	MRI	Physics	MR imaging and spectroscopy in prostate and colon cancer diagnostics.	Ingrid Gribbestad

Name	M/F	Nationality	Funding source	Scientific area	Master's background	Thesis title	Main thesis advisor
Toril Skandsen	F	Norway		MRI	Medicine	Moderate and severe traumatic brain injury. Magnetic resonance imaging findings, cognition and risk factors for disability.	Anne Vik
Kristine Skårdal	F	Norway	RCN	MRI	Physics	The role of self-gated MRI in murine models of heart failure.	Olav Haraldseth
Stein Roar Snare	M	Norway	RCN	Ultrasound	Cybernetics	Quantitative cardiac analysis algorithms for pocket-sized ultra-sound devices.	Hans Torp
Ole Solheim	M	Norway		Image guided surgery	Medicine	Ultrasound guided surgery in patients with intracranial tumours.	Geirmund Unsgård
Marte Thuen	F	Norway		MRI	Physics	Manganese-enhanced and diffusion tensor MR imaging of the normal, injured and regenerating rat visual pathway	Olav Haraldseth
Emilie Vallee	F	France	RCN	MRI	Medical Technology	New methods for localizing brain activity with Magnetic Reso-nance Imaging.	Asta Håberg
Mohammed Riyas Vettukatil	M	India	NTNU	MRI	Medical Technology	Identification and characterization of biomarkers using MR meta-bolomics: metabolic portraits of cancers and aerobic fitness.	Tone Bathen
Marius Widerøe	M	Norway	NTNU	MRI	Medicine	Magnetic resonance imaging of hypoxic-ischemic brain injury development in the newborn rat – manganese and diffusion contrasts.	Ann-Mari Brubakk
Jian Xu	M	Norway	NTNU	MRI	Medicine	Blood oxygen level dependent functional magnetic resonance imaging and diffusion tensor imaging in traumatic brain injury research.	Asta Håberg
Svein Arne Aase	M	Norway		Ultrasound	Computer science	Methods for improving quality and efficiency in quantitative echo-cardiography – aspects of using high frame rate	Hans Torp

PhD students with financial support from the centre budget who still are in the process of finishing studies

Name	M/F	Nationality	Scientific area	Master's background	Thesis topic	Main thesis Advisor
Birger Brekke	M	Norway	Ultrasound	Mathematics	Ultrasound imaging with high frame rate.	Hans Torp
Hans Herman Hansen	M	Norway	Ultrasound	Electronics	Ultrasound probe electronics.	Trond Ytterdal
Jarle Ladstein	M	Norway	MRI	Physics	New methods in functional MR Imaging.	Pål Erik Goa
Joakim Schistad Lund	M	Norway	Ultrasound	Medicine	Ultrasound imaging with high frame rate.	Brage Høyem Amundsen
Jørgen Moe Sandvik	M	Norway	Ultrasound	Electronics	Ultrasound probe electronics.	Trond Ytterdal
Lars Chr. Lervik Nilsen	M	Norway	Ultrasound	Medicine	Ultrasound imaging with high frame rate.	Asbjørn Støylen
Øystein Pettersen	M	Norway	Image guided surgery	Medicine	Ultrasound guided thoracic surgery.	Dag Ole Nordhaug
Kangqiao Shao	M	China	Ultrasound	Electronics	Ultrasound probe electronics.	Kjell Kristoffersen
Thomas Skaug	M	Norway	Ultrasound	Medicine	Ultrasound imaging of heart valves.	Bjørn Olav Haugen
Peng Wang	M	China	Ultrasound	Electronics	Ultrasound probe electronics.	Trond Ytterdal

Appendix 3

List of Publications

All 295 are peer reviewed scientific publications.
Of these 276 are full scientific papers in international journals with referee (265 are registered in the PubMed database at The National Institute of Health, USA as shown by the unique PubMed PMID number).
There are also 19 peer reviewed conference proceedings. In some areas of MI Lab activity (especially ultrasound probe electronics and image analysis) these proceedings are often the final publication of new scientific results

2015

1. Avdal J, Lovstakken L, Torp H. Effects of reverberations and clutter filtering in pulsed Doppler using sparse sequences. IEEE Trans Ultrason Ferroelectr Freq Control. 2015 May;62(5):828-38. doi: 10.1109/TUFFC.2014.006798. PMID: 25965677
2. Santos P, Tong L, Ortega A, Løvstakken L, Samset E, D'hooge J. Acoustic output of multi-line transmit beamforming for fast cardiac imaging: a simulation study. IEEE Trans Ultrason Ferroelectr Freq Control. 2015 Jul;62(7):1320-30. doi: 10.1109/TUFFC.2015.006996. PMID: 26168178
3. Andersen GN, Graven T, Skjetne K, Mjølstad OC, Kleinau JO, Olsen Ø, Haugen BO, Dalen H. Diagnostic influence of routine point-of-care pocket-size ultrasound examinations performed by medical residents. J Ultrasound Med. 2015 Apr;34(4):627-36. doi: 10.7863/ultra.34.4.627. PMID: 25792578
4. Graven T, Wahba A, Hammer AM, Sagen O, Olsen Ø, Skjetne K, Kleinau JO, Dalen H. Focused ultrasound of the pleural cavities and the pericardium by nurses after cardiac surgery: Ultrasound by nurses after cardiac surgery. Scand Cardiovasc J. 2015 Feb;49(1):56-63. doi: 10 .3109/14017431.2015.1009383PMID: 25611808
5. Dalen H, Gundersen GH, Skjetne K, Haug HH, Kleinau JO, Norekval TM, Graven T. Feasibility and reliability of pocket-size ultrasound examinations of the pleural cavities and vena cava inferior performed by nurses in an outpatient heart failure clinic. Eur J Cardiovasc Nurs. 2015 Aug;14(4):286-93. doi: 10.1177/1474515114547651. PMID: 25122616
6. Jakola AS, Senft C, Unsgaard G, Solheim O. Surgical management of eloquent supratentorial low-grade gliomas with special emphasis on intraoperative imaging. J Neurol Surg A Cent Eur Neurosurg. 2015 Mar;76(2):149-59. doi: 10.1055/s-0034-1393925. PMID: 25539070
7. Olsen A, Brunner JF, Indredavik Evensen KA, Finnanger TG, Vik A, Skandsen T, Landrø NI, Håberg AK. Altered Cognitive Control Activations after Moderate-to-Severe Traumatic Brain Injury and Their Relationship to Injury Severity and Everyday-Life Function. Cereb Cortex. 2015 Aug;25(8):2170-80. doi: 10.1093/cercor/bhu023. PMID: 24557637
8. Pintzka CW, Hansen TI, Evensmoen HR, Håberg AK. Marked effects of intracranial volume correction methods on sex differences in neuroanatomical structures: a HUNT MRI study. Front Neurosci. 2015 Jul 9;9:238. doi: 10.3389/fnins.2015.00238. PMID: 26217172
9. Chen CH, Peng Q, Schork AJ, Lo MT, Fan CC, Wang Y, Desikan RS, Bettella F, Hagler DJ; Pediatric Imaging, Neurocognition and Genetics Study; Alzheimer's Disease Neuroimaging Initiative, Westlye LT, Kremen WS, Jernigan TL, Hellard SL, Steen VM, Espeseth T, Huentelman M, Håberg AK, Agartz I, Djurovic S, Andreassen OA, Schork N, Dale AM; Pediatric Imaging Neurocognition and Genetics Study; Alzheimer's Disease Neuroimaging Initiative. Large-scale genomics unveil polygenic architecture of human cortical surface area. Nat Commun. 2015 Jul 20;6:7549. doi: 10.1038/ncomms8549. PMID: 26189703
10. Elvemo NA, Landrø NI, Borchgrevink PC, Håberg AK. A particular effect of sleep, but not pain or depression, on the blood-oxygen-level dependent response during working memory tasks in patients with chronic pain. J Pain Res. 2015 Jul 7;8:335-46. doi: 10.2147/JPR.S83486. PMID: 26185465
11. Pintzka CW, Håberg AK. Perimenopausal hormone therapy is associated with regional sparing of the CA1 subfield: a HUNT MRI study. Neurobiol Aging. 2015 Sep;36(9):2555-62. doi: 10.1016/j.neurobiolaging.2015.05.023. PMID: 26130062
12. Sølsnes AE, Grunewaldt KH, Bjuland KJ, Stavnes EM, Bastholm IA, Aanes S, Østgård HF, Håberg A, Løhaugen GC, Skranes J, Rimol LM. Cortical morphometry and IQ in VLBW children without cerebral palsy born in 2003-2007. Neuroimage Clin. 2015 Apr 14;8:193-201. doi: 10.1016/j.nicl.2015.04.004. PMID: 26106543
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