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Volym ASL 2024-004

A story about how MR-imaging grew up in Lund

Bertil RR PERSSON and Freddy STÅHLBERG

This story is dedicated to the memory of Ole Henriksen who suddenly died in the age of 61 years in 2006. He was MD chief physician, and adjunct professor, at Hvidovre Hospital in Denmark, and was our close collaborator in the start-up of clinical MR imaging Lund.

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A story about how MR-imaging grew up in Lund

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1. Conference in Munich (Bertil Persson)

One of my first assignments at the end of April 1981 as a newly appointed professor of Medical Radiation Physics at Lund University, was to participate at a European (EU) workshop in Munich. The topic was to discuss the possibilities of reducing patient exposure in X-ray diagnostics. There I presented an overview of different dose concepts in use, to estimate the radiation risks in X-ray diagnostics.

However, the greatest experience from the conference was the gatherings in the evenings, when we discussed all sorts of things over a Bavarian beer. I joined the participants from the UK who were conversing secretly by themselves in a corner. In the course of the discussion, it emerged that methods for medical imaging without X-ray radiation were under development at several places in

Great Britain. Instead of ionizing radiation, they applied magnetic fields and used the spin of hydrogen atoms to image the body's internal organs and tissues. A method they called "Magnetic Resonance Imaging" MRI.

When I heard this, I immediately understood that something extremely exciting was going on. I received information about which institutions and universities in the UK I should visit to learn more about the development of MRI.

2. The trip to England and Scotland (Bertil Persson)

As soon as I returned to Lund, I started planning a trip to England and Scotland to find out what was going on. I packed my wife Kerstin and our three children Annika 11, Christel 9, and Mikael 4, into the car for a long vacation. At first I visited, Dr. Radda in London, who was a biochemist, and told about the use of NMR spectroscopy to study various chemical processes in biological tissue.

The onward journey to various universities in England was a bit of a disappointment. I got the impression that the development was taking place in secret and I did not really get to know anything of importance about MRI.

Finally, we came to Aberdeen in Scotland where I had previously contacts regarding Nuclear Medical Imaging. Professor John Mallard who represented medical physics, was very accommodating and gave me a thorough review of the physics behind NMR imaging and how their image reconstruction algorithms worked (Mallard, 2006). Finally, he opened the door to the holiest of all - their home-built MRI device (Figure 1).

A jumble of coils and wires together formed the world’s first clinically useful NMR scanner. The figure below (Figure 1) shows one of the researchers Jim Hutchison, sandwiched between the 4 Helmholtz coils generating a homogeneous static magnetic field. Around him are transmitter and receiver antenna for radio communication with the hydrogen atoms in the body. In addition, a copper framework is visible that generates pulsed magnetic fields to obtain information about where in the body the signals are coming from.

Figure 2 shows the principle of how the homogeneous static magnetic field generated by the Helmholtz coils aligns the magnetic nuclear spin of the hydrogen atoms in the same direction. The interaction between the spin of the individual hydrogen atoms in a specific volume, create a common hydrogen magnetic vector. This vector is affected by an external radiofrequency signal which at a specific

frequency (the Larmor frequency) gets into resonance with the spin, whereby they absorb energy and change direction.

When the external radio transmitter switched off, the spin of the hydrogen atoms tends to return to its original position, whereby the absorbed energy radiates at the same frequency and recorded by the radio antenna.

Figure 1

When I visited Professor John Mallard at Aberdeen University in Scotland, he showed me this home-built MR apparatus (Mallard, 2006).

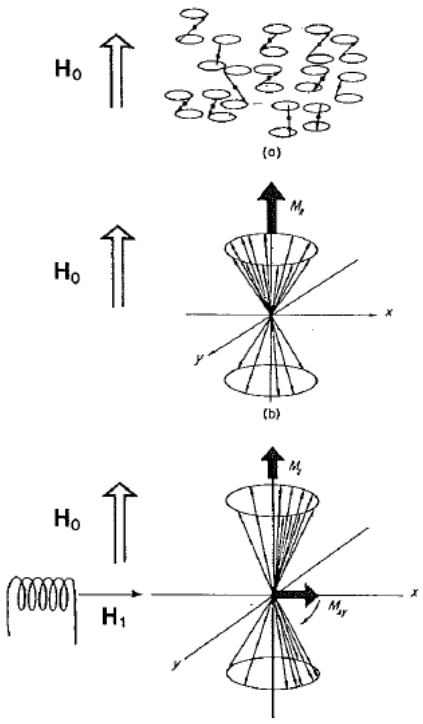

Figure 2

The spin of the hydrogen atoms aligns itself in a static magnetic field whereby creating a magnetic vector, which affected by an RF pulse changes direction. When the magnetic vector returns to the original position before the pulse, a signal appears that used to generate an image.

As the Larmor frequency is proportional to the magnetic field strength, the gradient fields generated by the large rectangular frames locate where in the body the radio signals are coming from. By repeating the process countless times, information gathered from selected volume elements of the body to create an image, reconstructed by the computer.

I absorbed as much information as possible, which I collected for lectures to spread the message when I returned in Lund.

We established a close collaboration with Aberdeen and already in December 1981, I myself was located in their MR scanner and imaged my heart. The MR image adorns the cover of the book that summarizes my lectures on "Medical

applications of nuclear spin resonance NMR" published in 1982 in Swedish (Figure 3).

3. Research activities start in Lund

Research activities in Lund began with studying proton relaxation properties of various biological tissue samples. Every morning one of our biomedical assistants (Carin Lingård) collected fresh pig brains from the slaughterhouse in Kävlinge. Different parts of brain tissue were analysed in a Praxis brand NMR spectrometer with a permanent magnet connected to an Apple computer.

Collaboration established with the neuropathologist Arne Brun, who assigned his doctoral student Elisabeth "Bitte" England. Her task was mapping the magnetic relaxation properties of various parts of the brain, which became the basis of her doctoral thesis (Brun et al., 1984 , Englund et al., 1984, Gyöffry-Wagner et al., 1984 , Gyöffry-Wagner et al., 1985, Larsson et al., 1985, Englund et al., 1986a, Englund et al., 1986b, Gyöffry-Wagner et al., 1986, Larsson et al., 1986).

In parallel with relaxation measurements, work was underway to build our own version of an NMR scanner. Unlike Aberdeen's Helmholtz-coil, the Lund magnet concept was a soft iron frame magnetized with electromagnets (Figure 7b).

4. The NMR book (Bertil Persson)

As soon as I got back to Lund, I started writing up my experiences for a lecture series. The lecture notes completed on February 15, 1982 in a book entitled "*Medical Applications of Nuclear Spin Resonance NMR*" which was published in 1982 (Persson, 1982).

The book contains the following chapters:

1. Basic principles
2. NMR spectroscopy
3. Principles and methods of NMR scanning
4. Medical Applications of NMR
5. Biological effects of Magnetic Fields and RF radiation at Medical in vivo applications of NMR
6. Bibliography
7. Index

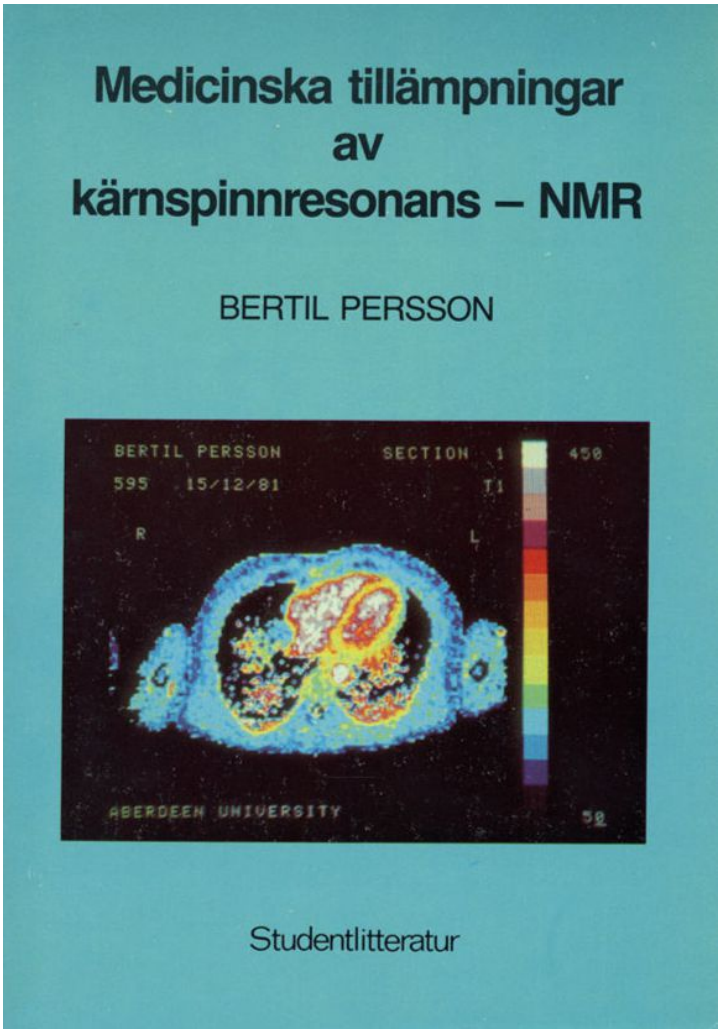

Figure 3

The cover image shows an MRI image of my chest with the red oxygenated blood flowing into my heart. The picture taken on December 12, 1981 with the world's first clinically useful MR scanner at Professor John Mallard's Department of Medical Physics at the University of Aberdeen, Scotland.

5. The Workshop in Hörby, Skåne

The workshop on "Medical applications of NMR" arranged under the auspices of the Swedish Association for Radiation physics took place on 19-20 November 1982, i.e. exactly 42 years ago, at the County Council's course yard at the artificial insemination station in Hörby, Skåne. There the seed sown for the fruitful development of clinical NMR activity in Lund!

SVENSK FÖRENING FÖR RADIOFYSIK
SWEDISH ASSOCIATION OF PHYSICISTS IN MEDICINE

INBJUDAN TILL WORKSHOP OM MEDICINSKA TILLÄMPNINGAR AV NMR
19-20 nov 1982, Landstingets kursgård i Hörby (Skåne)

Program

Friday 19 November 1982

9-10 Arrival, coffee
10-12 Electromagnetic theory, NMR theory, and NMR spectroscopy (Lecturer: Bertil Persson)
12-14 Lunch and discussions
14-16 Principles of NMR scanning (Lecturer: Bertil Persson)
16-17 Demonstration of teaching system, principles and Fourier Transforms (Lecturer doctoral student Freddy Ståhlberg)
18-21 Dinner. Presentation of commercial NMR systems

Saturday 20 November

9-11 Detailed structure and function of the Lund MR scanner (Lecturer Doctoral student Magnus Bolmsjö)
11-12 Panel discussion on medical applications of NMR
12- Lunch and closing

The cost of course expenses, food and lodging was SEK 350.

6. Lund's first MR scanner

After returning from Aberdeen in 1981, I contacted the engineers at the physics department who designed and built Lund University's Synchrotron "LUSY", the predecessor of the MAX IV. They were experts in constructing magnets of all kinds so I asked how to construct a magnet with a large volume of constant magnetic field. They proposed a so-called "Window frame" magnet made of soft iron that magnetized with coils in the frame, Figure 4.

We designed a professionally fabricated version with flat-ground iron foundations and water-cooled coils that generated the magnetic field (Figure 4).

Figure 4

Here I am behind version 2 of the window frame magnet with the tube surrounded by x-y-z gradient coils and RF coil.

Figure 5

Here the NMR gang is gathered in the MR laboratory from the left in the picture Lennart Bertenstam (civil engineer ✝2015), Freddy Ståhlberg (doctoral student, now professor em), Börje Blad (civil engineer, doctoral candidate), Magnus Olsson (doctoral student), Kjell-Åke Carlsson (instrument maker ✝2016), Elna Marie Larsson (physician diagnostic radiology, doctoral student now professor em.), Bertil Persson (now professor emeritus), Lars Malmgren (civil engineer, doctoral student), Stefan Petersson (doctoral student). Note the Osborne computer in the foreground with a 2.5 inch monitor and two 156 kb floppy disks as working memory.

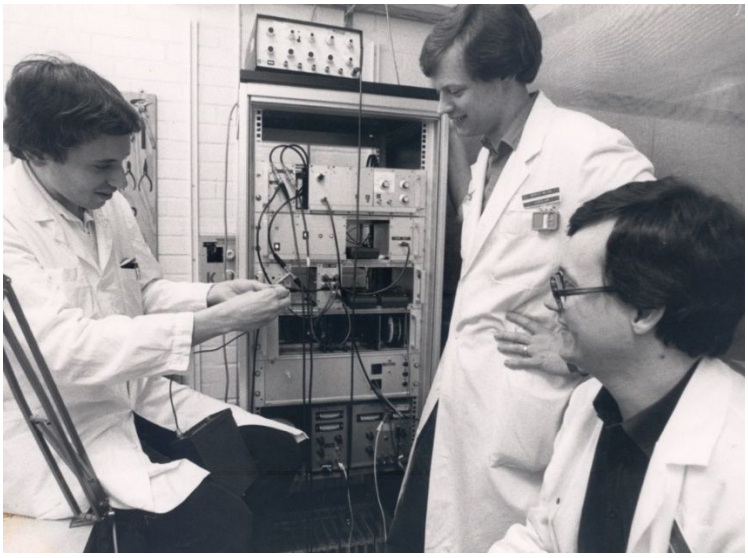

Figure 6

Three happy engineers Lars Malmgren, Börje Blad, Lennart Bertenstam (✝2015).figure out something in NMR electronics "Something Very Funny",

The first Symposium on "NMR imaging": *1st Symposium on Nuclear Magnetic Resonance (NMR) in medicine and biology* took place during 14 - 15 October 1983 in Geneva, Switzerland.

There we presented our "window-frame" NMR scanner, which was published in the proceedings (Figure 7b) (Persson et al., 1984).

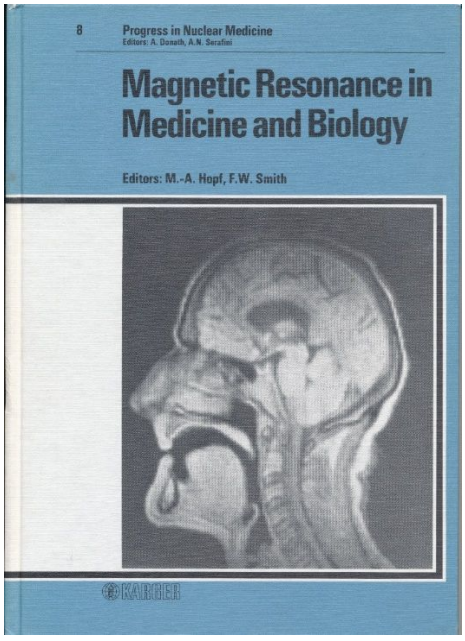

Figure 7a

Proceeding of the 1st Symposium on Nuclear Magnetic Resonance (NMR) October 14 - 15, 1983, Geneva, Switzerland

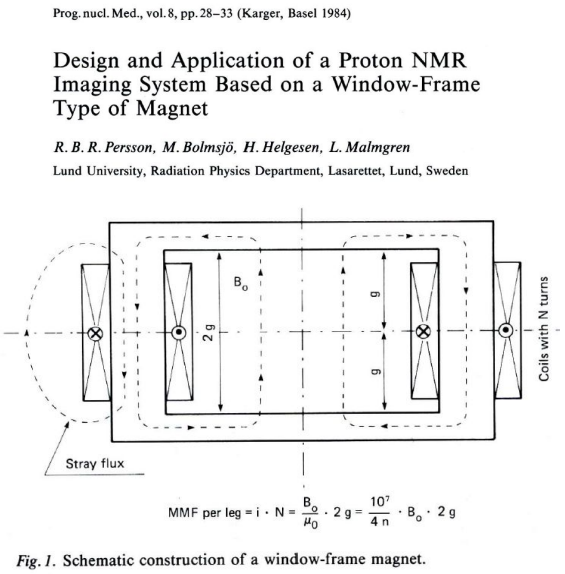

Figure 7b

Excerpt from the presentation "The design and application of a proton NMR imaging system based on a “window-frame magnet".

At the conference in Geneva, a clinical work from Lund presented by MD Jan Tennvall, on investigations of relaxation times in malignant Thyroid tumours and in normal human thyroid tissue (Tennvall et al., 1984). This presentation showed the breadth of clinical NMR research in Lund with participants from several clinical specialties such as oncology, pathology, ear-nose-throat surgery, neuro-pathology, diagnostic radiology, and medical radiation physics.

Prog. nucl. Med., vol. 8, pp. 142–148 (Karger, Basel 1984)

Studies of NMR-Relaxation-Times in Malignant Tumours and Normal Tissues of the Human Thyroid Gland

J. Tennvall[a], A. Biörklund[b], T. Möller[a], M. Olsson[c], B. Persson[c], M. Åkerman[d]

Departments of [a]Oncology, [b]Otorhinolaryngology, [c]Radiation Physics, and [d]Cytodiagnostics, University Hospital, Lund, Sweden

The relaxation study performed at 37 °C on fresh human thyroid samples (0.5-3.5 g) at a frequency of 10.7 MHz with the pulse sequences: (90°-τ-90°) for the relaxation time T1 and (90°-τ-180°-τ) for the relaxation timeT2 .

The results correlated with quantitative histopathological examinations estimating the proportions of colloid, fibrosis, necrosis and haemorrhage in benign and malignant tissue shown in Figure 8. No sample showed a mixture of benign and malignant thyroid cells.

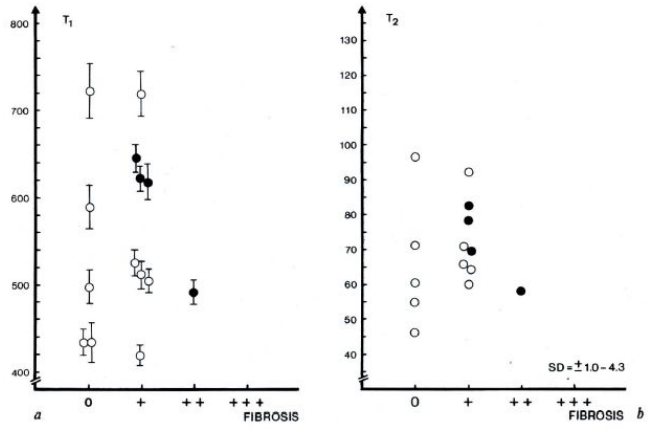

Figure 8.

The relationship between the degree of fibrosis in carcinoma●, and benign tissue○ with T1 values (Left diagram) and T2 values (Right diagram)

Three of four samples with papillary carcinoma had the same proportions of fibrous tissue (and colloid). They had a narrow range of T1 and T2 values. One sample had a greater proportion of fibrous tissue with lower values for both T1 and T2.

●,Carcinoma; ○: Benign lesion.

At the following year's congress: First Congress of The European Soc. of Magn. Resp. in Medicine and Biology, (M.-A. Hopf and G. M. Bydder, eds., London 1984, pp. 234–243) a long series of works from Lund was presented. (Gyöffry-Wagner et al., 1985, Larsson et al., 1985, Malmgren et al., 1985, Olsson et al., 1985, Persson and Ståhlberg, 1985, Ståhlberg et al., 1985a, Ståhlberg et al., 1985b).

7. Diagnostic radiology (Freddy Ståhlberg)

Freddy Ståhlberg joined the MR group early on and with his teaching skills, he became an important spreader of the knowledge about MR-imaging as well as guidelines concerning hazards and health effects of NMR in vivo measurements (Persson and Ståhlberg, 1985). Together we published the book entitled: *Health and Safety of Clinical NMR Examinations* (Persson and Ståhlberg, 1989).

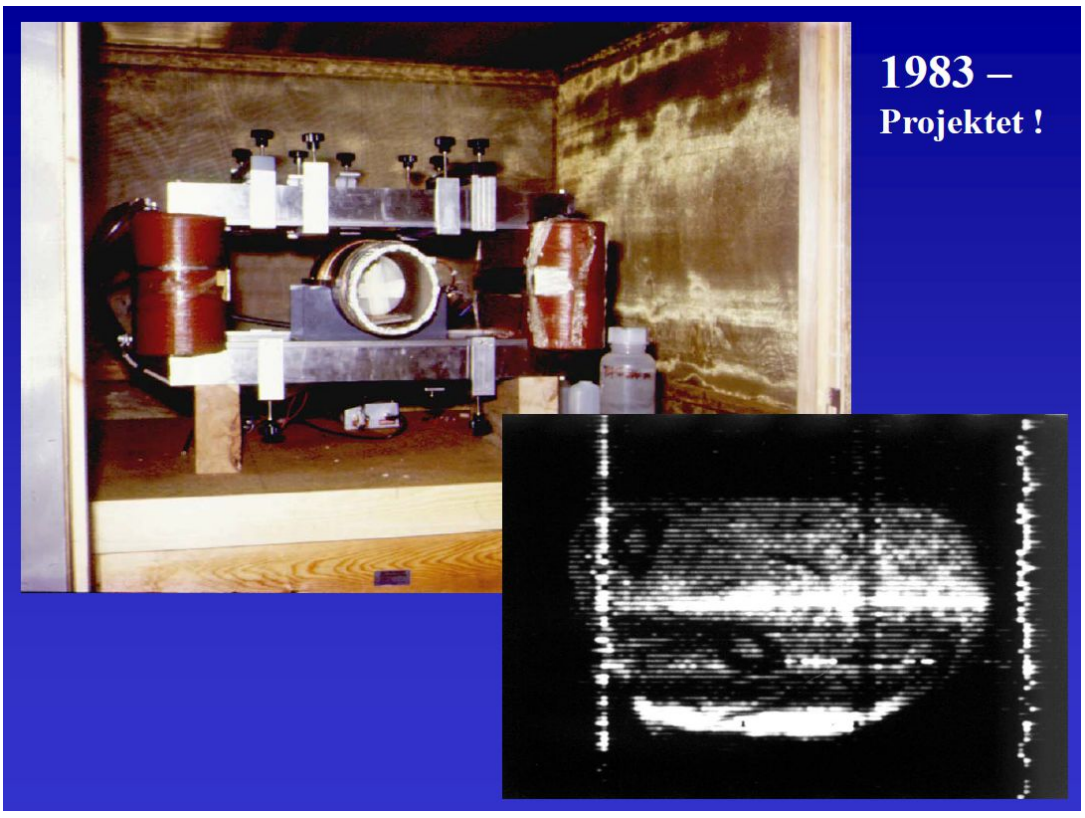

Figure 9
The first NMR image in Lund of a human subject 1983, Freddy Ståhlberg's forearm

Through contacts with Ole Henriksen and other research colleagues in Copenhagen, a research collaboration established early on between Lund and Hvidovre Hospital, which in the mid-1980s had world-leading MR equipment at its disposal. Here, Freddy Ståhlberg got an outlet for his ambitions to develop flow MR imaging which became his doctoral. thesis (Ståhlberg and Persson, 1985, Ståhlberg et al., 1985a, Ståhlberg et al., 1985b, Malmgren et al., 1992, Ståhlberg et al., 1992a, Ståhlberg et al., 1992b, Wirestam et al., 1997).

A number of doctoral students from Lund were active on both sides of the strait for about ten years.

Freddy Ståhlberg also established a close collaboration with Uppsala University and Karolinska Hospital in Stockholm (Nordell et al., 1988, Ståhlberg et al., 1985a, Stahlberg et al., 1992).

The development of MR in diagnostic radiology increased exponentially as seen in Figure 10, where Freddy Ståhlberg predicted that the development to clinical seven tesla (7T) MR-imaging reached in October 2008.

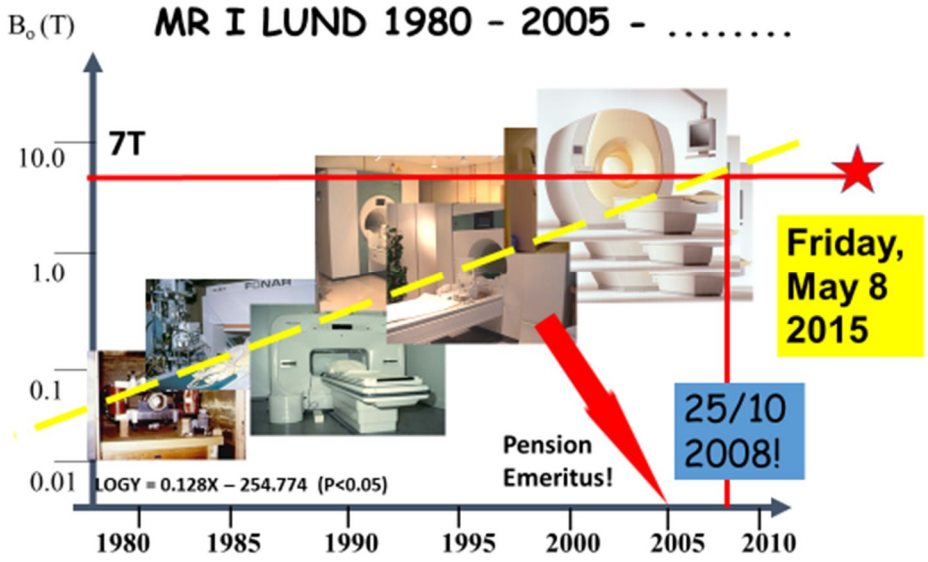

Figure 10

Freddy Ståhlberg's prophecy!

The development of commercial systems took off and soon MRI was a clinically established branch of diagnostic radiology. Bertil Persson retired 2005 and the 7 tesla magnet installed 2015.

Magnetic resonance technology has meant a revolution in medical image diagnostics and follow-up of various therapy methods. Although it has been available for more than four decades, it is undergoing constant technological development.

In terms of applications, Freddy Ståhlberg focused on the topics of 7 tesla MR, which most likely should become of significant importance to brain imaging, ^{1}H-spectroscopy, and high-resolution functional MRI (Moser et al., 2012).

With the extensive MR research activity, he created in Lund, with unique competence of more than twenty active research physicists and medical doctors behind him, Freddy Ståhlberg managed to get the National 7 Tesla MR research facility established in Lund 2014 in fierce competition.

Today's magnetic cameras are far superior to the older magnetic resonance cameras in terms of both image quality and speed. New doors open for functional and molecular imaging with applications in cardiology, neurology, psychiatry and several medical disciplines (Persson, 2023).

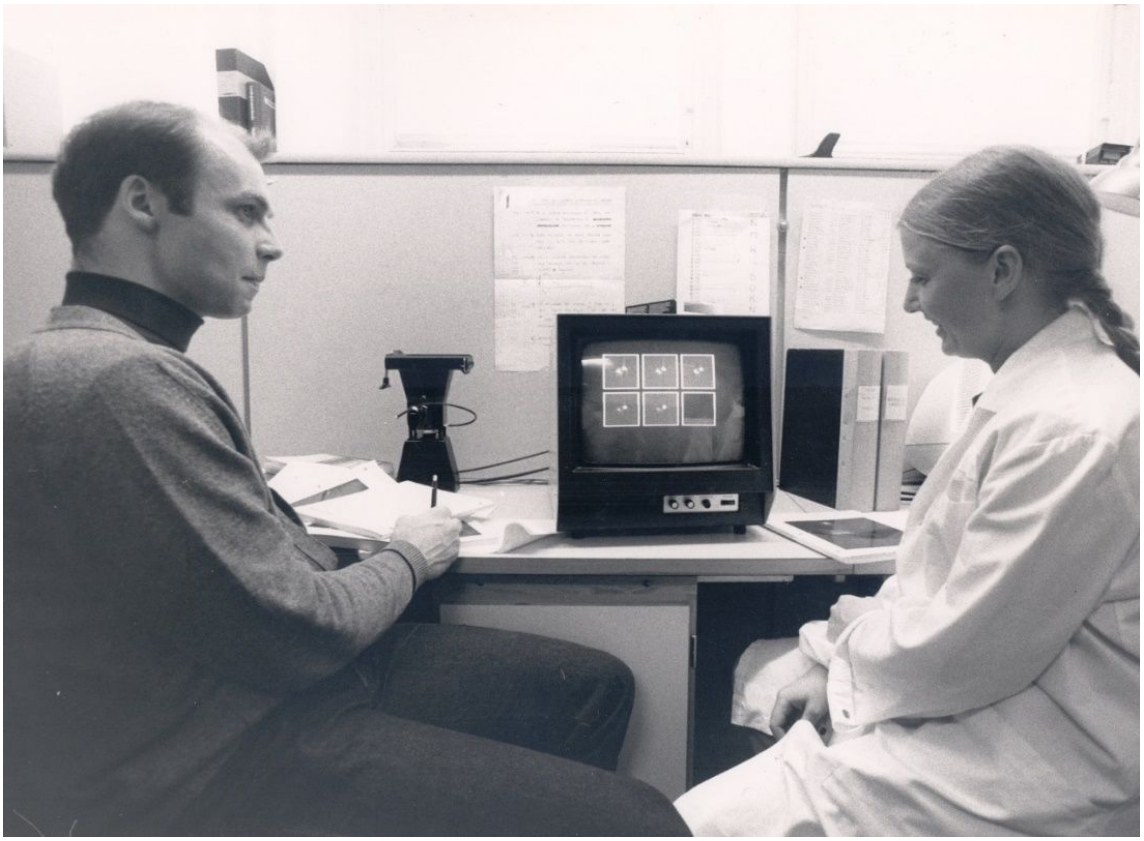

Figure 11

Stefan Petersson inaugurates Lund's first clinical MRI assistant Titti Owman in "Something Very Funny" which in Swedish is ”*Något Mycket Roligt”* (NMR)

8. Summary

A story about how Magnetic Resonance Imaging grew in Lund

One of my first assignments as a newly appointed professor of Medical Radiation Physics at Lund University was to go to Munich at the end of April 1981 to participate in a European (EU) workshop on the possibilities of reducing patient exposure in X-ray diagnostics. It emerged from the participants from Great Britain that methods for medical imaging without X-ray radiation developed in several places in Great Britain. Instead of ionizing radiation, magnetic fields and the spin of hydrogen atoms used to image the body's internal organs and tissues. The method called "Magnetic Resonance Imaging" MRI.

When I heard this, I immediately understood that something extremely exciting was going on and immediately went to the UK. There I contacted Professor John Mallard who represented medical physics at Aberdeen University. He was very accommodating and gave me a thorough review of the physics behind NMR imaging, and the image reconstruction algorithms.

When he showed the world's first clinically useful NMR scanner with 4 Helmholtz coils that generate a homogeneous static magnetic field in a jumble of coils and wires, I was hooked.

A close collaboration was established with Aberdeen and already in December 1981, I myself was in their MR scanner and pictured my heart which adorns the cover of my book. It summarizes my lectures on "Medical applications of nuclear spin resonance NMR" held in November 1982 at a workshop at the County Council course yard at the artificial insemination station in Hörby, Skåne. There the seed sown for the fruitful development of clinical NMR activity in Lund!

Research activities in Lund began with studying hydrogen relaxation properties in various biological tissue samples. In parallel, work was underway to build our own version of an NMR scanner based on our own concept of a soft iron frame that magnetized with electromagnets.

The first Symposium on "NMR imaging": 1st Symposium on Nuclear Magnetic Resonance (NMR) in medicine and biology took place during 14 - 15 October 1983 in Geneva, Switzerland. There we presented our "window-frame" NMR scanner and the results of our research in Lund.

Freddy Ståhlberg joined the MR group early on, and with his teaching skills, he became an important spreader of knowledge about MR-imaging as well as guidelines concerning hazards and health effects of NMR in vivo measurements.

Through contacts with research colleagues in Copenhagen, a research collaboration established early on between Lund and Hvidovre Hospital, which in the mid-1980s had world-leading MR equipment at its disposal. Here, Freddy Ståhlberg got an outlet for his ambitions to develop flow MR-imaging, which became his doctoral thesis.

A number of doctoral students from Lund were active on both sides of the strait for about ten years. This led to the MR research group in Lund soon growing to more than twenty active research physicists and doctors. With this unique competence behind him, Freddy Ståhlberg managed to get the National 7 Tesla MR research facility established in Lund in 2014 in tough competition.

Magnetic camera technology has meant a revolution in image diagnostics and follow-up of various therapy methods. Although it has been available for more than four decades, it is in constant technological development. Today's magnetic resonance cameras are far superior to older magnetic cameras in terms of both image quality and speed. New doors are opening for functional and molecular imaging with applications in cardiology, neurology, psychiatry and several other medical disciplines.

Acknowlegement

This story is dedicated to the memory of Ole Henriksen who suddenly died in the age of 61 years in 2006. He was MD chief physician, adjunct professor, at Hvidovre Hospital in Denmark, and was our close collaborator in the start-up of clinical MR imaging.

Ole Henriksen's very rich abilities and his winning nature have led to an extensive collaboration with colleagues all over the world who will remember him with pleasure, and for his great efforts with the greatest recognition.

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Born : October 12, 1938 in Malmoe, Sweden.
1970 PhD, 2004 MD h.c.
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In April 1981, I contacted Professor John Mallard who represented medical physic at Aberdeen University in Scotland. He was very accommodating and gave me a thorough review of the physics behind NMR imaging and the image reconstruction algorithms. When he showed the world's first clinically useful NMR scanner with 4 Helmholtz coils that generate a homogeneous static magnetic field in a jumble of coils and wires, I was hooked and decided to build one in Lund. Research activities in Lund began with studying proton relaxation properties in various biological tissue samples. In parallel, work was underway to build our own version of an NMR scanner based on our own concept of a soft iron frame that magnetized with electromagnets.

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Thesis 1987 PhD,
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Permanent Secretary/Treasurer of Royal Physiographic Society of Lund

"*I've always felt like a surfer on a wave*"

Freddy Ståhlberg joined the MR group early on and with his teaching skills; he became an important spreader of MR-Imaging and MR-safety knowledge within the medical community. Through contacts with research colleagues in Copenhagen, a research collaboration established between Lund and Hvidovre Hospital, which in the mid-1980´s had world-leading MR equipment at its disposal. Here, Freddy Ståhlberg got an outlet for his ambitions to develop flow MR imaging, which became his doctoral thesis. His MR-research group at Lund University has grown to more than 25 physicists and medical doctors. With this unique competence behind him, Freddy Ståhlberg managed to get the *National 7 Tesla MR-research facility* established in 2014 at tough competition to Lund.