30 years of MRI research by Christopher Wiggins, PhD

Recently I was reminded of just how long I have been working in the field of MRI. The reminder came about in an article in the Scottish television company STV's news edition entitled "First MRI goes on display in Aberdeen hospital art gallery" [1]. The article described how this system, the Aberdeen Mark One, had just been reassembled in the Suttie Arts Space Gallery. The Mark One - one of the first three whole-body MRI systems ever constructed – is notable in MRI history in several facets. Particularly it was the scanner where the first ever diagnostic images were made, as well as being where the basis of most modern MRI techniques – 'Spin-Warp' phase encoding – was invented and developed.

First MRI: Creator Eddie Stevenson with his machine. STV

My start in the field was somewhat accidental. I was an undergraduate student at Edinburgh University, and was trying to decide which career path to take. With both a father and a maternal grandfather having been research physicists, research always seemed the most natural path. However I decided that it would be good to get some experience in a research lab before my final year, so that I could get the feel of how it felt in practice. I had once toured the Medical Physics department at the Royal Infirmary in Edinburgh (where there was an early commercial MRI system, an M&D 800, which was from a spin-off company from Aberdeen) and liked the idea of applying physics to medicine. I therefore wrote to the Medical Physics department in Aberdeen, asking whether they had a position for a student for the summer. They wrote back inviting me for an interview, as they had a position for a student in the cyclotron unit connected to their PET (Positron Emission Tomography) scanning center. I duly took the train to Aberdeen while reading up on cyclotrons (I believe it was the book The Cyclotron by W.B. Mann, published by Methuen. As I recall this was pretty much a do-it-yourself manual for how to construct one!). However when I got to the department all they talked about was MRI. Later I found out that there had been a severe fire in the cyclotron unit, and so any work for a student was gone (other than sweeping up the ashes, I guess) and so they decided that MRI was a better option. Thus I spent the summer working under Dr. Tom Redpath, measuring gradient non-linearities, developing a pneumatic belt for respiratory measurements, and using the latter to try to implement a technique called ROPE [2]. One of the PhD students at the time is now well known in the MRI community, both in general and particularly in the Netherlands: one David Norris (now at the Donders in Nijmegen). After completing my degree in Edinburgh, I then attended the Masters in Bio-Medical Physics in Aberdeen, completing the research part of my thesis – Techniques for Fat-Water Discrimination - under David Lurie. I then worked there for a year as a Research Assistant in the Bio-Medical Physics department.

So what was this system like? Well, in modern terms, this system would be classified as Ultra-LowField, as it was operated at 400 Gauss, which is 0.04 Tesla. In fact the encoding gradients on the systems at Scannexus can effectively exceed this, and the magnets two order of magnitude stronger. The basis of the system was a 4-core, resistive electromagnet. Since this was a resistive system (as opposed to the superconducting magnets on most modern clinical systems), you had to wait about half an hour after turning it on for the field to stabilize. The console was a Digital PDP- 11, considered a minicomputer at the time, but taking up two tall equipment racks. I recall that, for some reason, this was a 110V system, so the first thing you had to switch on was a big 220V to 110V converter, after which the system booted from a removal disk the size of a dinner plate. To program the scanning itself, the pulse sequence was written in Z80 assembly language, compiled, and then ‘burnt’ onto an EPROM (Erasable Programmable Read-Only Memory) which was literally a computer chip with pins. Having written the program to the chip, you would take the chip out of the burner, get up, go into the scanner room, stop the scanner, swap the chip, turn the scanner on, and then check with an oscilloscope if it was working the way you wanted. If not, you swapped the chip back, put it under ultraviolet light for 10 minutes to erase it, and started again. It was quite an improvement for me when I started my PhD at the University of Cambridge, as the systems there were a little more modern and you could actually compile and run a sequence without getting out of your seat! There is a partial history of MRI in Aberdeen on a site created by Jim Hutchison [3], from whom I learned a tremendous amount.

In the intervening years I have moved between several countries, at gradually increasing MRI field strength. My PhD at Cambridge was in non-medical applications of MRI, particularly for polymers and studying reaction injection molding. This involved creating RF coils around vacuum dewared vessels, as well as a large amount of hardware hacking. It became a bit of a joke that I would ask Adrian Carpenter (my supervisor) and Cliff Bunch (our electronics engineer) if it was OK if I disassembled and reused some piece of equipment, and they would say “Sure, whatever. So long as you put the kettle on for a pot of tea.” As a side project, I ended up with a chapter on bread and cake baking in MRI – perhaps the best smelling studies I have ever done! From there I spent a bit over a year at Yale, working under Robert Shulman and doing fMRI work on a system at 2.1 Tesla. It was quite an old system, and it was quite difficult to get it set up for these studies. The resolution and coverage was extremely limited, with an image matrix of 32x64, 4.8x2.5mm inplane resolution, and only four 5mm thick slices. Slice positioning was crude, with the localizer image displayed as if it was a 2D spectrum, from which you read off the frequency offsets and manually typed them into a frequency list for the fMRI experiment itself. There were no computer driven stimuli, and instead a co-worker had to be in the scanner room and delivering the stimuli (touching the subject or reading words to the subject through a form of stethoscope) in time with the scanning. Still, a PNAS paper came out of this work [4].

I was then recruited by David Norris to come and work at the newly-founded Max Planck Institute for Cognitive Neuroscience (now Human Cognitive and Brain Sciences) in Leipzig, Germany. This was an exciting time in many ways. The institute was just being built, the first Max Planck Institute to be set in what had been East Germany. We took delivery of one of the first of the latest generation of 3 Tesla MRI systems, a Bruker 3 Tesla MedSpec. There were numerous teething problems, but the team gradually worked through these to finally end up with what was a worldclass fMRI setup. I remember well the day when David, having been in a meeting with the director (Yves von Cramon) where the lack of progress on fMRI had been discussed, came in the MRI console room to see how things were going. In a moment of excellent timing, we had just fixed the last major bug in the system and had just acquired some excellent fMRI from a simple visual task, which was displayed on the scanner console screen. David took one look at the screen, picked up the phone, dialed von Cramon and said "It works!" That system soon became an fMRI workhorse, with many, many studies being conducted on it. It was only decommissioned in early 2015, after about 18 years of nearly continuous use.

After a few years in Leipzig I had a desire to go to yet higher magnet field, and found out about the 7 Tesla project in Massachusetts General Hospital in Boston. Greg Sorensen hired me to work with people like Larry Wald and Andreas Potthast. The 7 Tesla there was one of the earliest installed – the third, I think – and was purchased separately from the electronics console from Siemens, which was adapted from 1.5 Tesla. Andreas Potthast, a very skilled engineer from Siemens who taught me a fantastic amount, found all sorts of neat hacks to make the system work. One of these involved taking out a mixing stage in the RF chain, which has a side effect of mirroring all the offset frequencies. One of the minor side effects of this was that the images would come out with left and right swapped, which was relatively easy to fix in the system configuration. Less easy was fat saturation, where the offset frequency compared to water scales with field strength. Since the system still thought it was at 1.5 Tesla, the software would calculate the wrong offset. The removal of the mixing stage meant it was also offset in the wrong direction! Hence a lot of my early time there was software adaptations to make the system appear to work correctly for the users. Thankfully, during this time MGH became a significant collaboration partner of Siemens, and the system gradually became more and more like a product scanner. This included the complete replacement of the electronics with better integration, to the level that all the present Siemens systems have, which was the first 7 Tesla to use a 32 channel receive coil.

By this stage, my magnet field addiction was starting to be apparent, and I was recruited by Denis le Bihan to the newly created facility, NeuroSpin. This was a new laboratory within the CEA (Commissariat à l'énergie atomique et aux énergies alternatives), the French atomic energy administration. There, as part of the Iseult / INUMAC project, an 11.7 Tesla magnet is being constructed. This is based on a unique design conceived by the inimitable Guy Aubert. It involves "double pancake" coils that sit in a bath of superfluid Helium. It is quite a long magnet and will have additional coils to be 'self-shielded', resulting in magnet that will be about 5 meters in height, width and length, with a total weight of around 130 tons! I was System Engineer on this project while I was there, helping to ensure that the final magnet was suitable for use for MRI. Unfortunately, since nearly everything about this system is new and experimental, the development is very slow, with many significant delays. Indeed, after the five years I spent there and an additional four in Maastricht, the 11.7 Tesla is only due to be delivered in late summer of this year. In the meantime, though, I was also system manager of NeuroSpin's 7 Tesla system, including being the first person to demonstrate the orientation dependence of the $T2^*$ of white matter at UHF [5].

When I heard about the Brains Unlimited project in Maastricht, it immediately seemed very attractive. Three state-of-the-art scanners under one roof, in an easy to reach academic campus, next to a large hospital! I started making enquiries and was soon recruited as the Senior Staff Scientist (now Senior Operations and Technical Development Officer) for Brains Unlimited BV, which is now Scannexus BV. With the help of the Scannexus team as well as collaborators in UM (particularly from the Cognitive

Neuroscience department), we now have a well running facility. In particular, our UHF systems are being used extensively, and the Maastricht research community contributed to three separate papers in the MAGMA Special Issue*: Ultrahigh Field MR: Cutting Edge Technologies Meet Clinical Practice* [6], which I find a nice indication that we are taking our place amongst the leading UHF facilities in the world.

[1] http://stv.tv/news/north/1343804-historic-scanner-goes-on-display-in-aberdeen-hospital-art-gallery/
[2] J Comput Assist Tomogr. 1985 Jul-Aug;9(4):835-8. Respiratory ordered phase encoding (ROPE): a method for reducing respiratory motion artefacts in MR imaging. Bailes DR, Gilderdale DJ, Bydder GM, Collins AG, Firmin DN.
[3] http://www.hutch73.org.uk/MRIhist/index.html
[4] Proc Natl Acad Sci U S A. 1997 Jun 24;94(13):6989-94. "Willed action": a functional MRI study of the human prefrontal cortex during a sensorimotor task. Hyder F1, Phelps EA, Wiggins CJ, Labar KS, Blamire AM, Shulman RG.
[5] Proceedings of the 16th Annual Meeting of ISMRM; Toronto, Canada. 2008. p. 237. Orientation dependence of white matter T2* contrast at 7 T: A direct demonstration. Wiggins CJ, Gudmundsdottir V, Le Bihan D, Lebon V, Chaumeil M.
[6] Magnetic Resonance Materials in Physics, Biology and Medicine, Volume 29, Issue 3, June 2016 Special Issue: Ultrahigh Field MR: Cutting Edge Technologies Meet Clinical Practice Issue Editors: Thoralf Niendorf, Markus Barth, Frank Kober, Siegfried Trattnig