

# Magnetic Resonance in Medicine *HIGHLIGHTS*

## 2020 Young Investigator Awards

Meet the I.I. Rabi and  
W.S. Moore YIA finalists

## Larry Wald

ISMRM's sustainable future

## Editor's Picks

## An Informal History of the ISMRM and SMRT in Australia and New Zealand

## Making the leap in imaging performance



- ▶ Get the most out of your MR scanner
- ▶ Tools for MR sequence development and image reconstruction

Visit us at our ISMRM booth

# Welcome to *Magnetic Resonance in Medicine Highlights*

**A**s you are probably aware, this year's ISMRM Annual Meeting was originally planned for Sydney in April, but in response to the COVID-19 global pandemic the meeting will now be held virtually, in August. By the time it was announced, this volume of the *Highlights* magazine had already been completed and was nearly printed, including a cover story on the past, present and future of MR research in Australia and New Zealand that was meant to celebrate the Sydney meeting. We have decided to keep the cover story and the rest of the magazine content as is – a reflection of the meeting as originally planned, and we hope you enjoy reading it!

• • •

There have been lots of changes to *MRM and Highlights* this past year. Not only has Peter Jezzard taken over from Matt Bernstein as editor-in-chief, the *Highlights* team has also undergone a significant reorganization and change in leadership. Nikola Stikov, who has been the driving force and champion of *MRM Highlights* since its inception in 2015, has stepped down as *MRM* deputy editor for scientific outreach. Nikola, along with Erika Raven and in later years Atef Badji have shepherded the *Highlights* initiative through years of Q&As and interviews, and four volumes of *Highlights* print magazines distributed at the annual meetings. While Erika has also stepped down from her role with *Highlights*, Atef has stayed on and is joined by Matthieu Boudreau, the new *MRM* deputy editor for scientific outreach and *Highlights* editor for digital content, and me, the new *Highlights* magazine editor.

*Highlights* has become incredibly successful at its mission of expanding the impact and reach of *MRM* research articles, and it owes much of that success to the leadership of Nikola and Erika. They managed to mobilize scores of volunteers (myself included, back in 2016), engage with featured authors, and build a recognizable brand that has become a fixture of the ISMRM community. This even includes the introduction of edited video Q&As, which are hosted on the *MRM Highlights* YouTube channel, many of which have been transcribed for inclusion in this year's magazine.

With the leadership changes at *MRM and Highlights*, a few changes are coming to the *Highlights* digital content and magazine. For example, *Highlights* interviews will now be chosen on the basis of reproducible research practices. To learn more, I encourage you to read Mathieu's "What's new with *MRM Highlights* in 2020" blog post on the *Highlights* website, which puts forth his new vision for *Highlights* digital content. As for the magazine, we've still retained a lot of the features that have been mainstays of the magazine in previous years; the outgoing ISMRM president interview, and Q&As from the past year are still featured in this volume.

However, there is a lot of new content that Peter and I have introduced to this year's magazine. Some features focus on historical content that revisits the past, including an interview about past meetings and MR history in Australia, and a look back at the Young Investigator Award winners from the 1995 meeting in Nice, France. We also have new features that are forward looking – these include an ISMRM Membership-At-A-Glance infographic, providing a demographic overview of our society, and profiles of this year's batch of Young Investigator finalists, for both the *MRM* I.I. Rabi and JMRI W.S. Moore awards. With these changes, volume 5 of the *Highlights* magazine will serve a more general role as a companion magazine to the annual meeting, and we hope you're as enthusiastic about these new additions as we are.

It takes a village to put together a magazine like this, so I'd also like to briefly acknowledge the contributions of the ISMRM Central Office, particularly Roberta Kravitz, and the numerous contributors who helped perform interviews, write articles, and transcribe videos for this magazine. As a volunteer-led initiative, *Highlights* depends on the contributions of readers like you, and we've been fortunate enough to have an amazing team this year!

**Mark Chiew**

*MRM Highlights* Magazine Editor

**AUGUST 2020 / VOLUME FIVE**

EDITOR-IN-CHIEF

**Peter Jezzard**

*Magnetic Resonance in Medicine*

HIGHLIGHTS MAGAZINE EDITOR

**Mark Chiew**

*Magnetic Resonance in Medicine*

HIGHLIGHTS EDITOR FOR DIGITAL CONTENT

**Mathieu Boudreau**

HIGHLIGHTS EDITOR

**Atef Badji**



**WILEY**

## CONTENTS

### FOREWORD

#### 1 WELCOME TO MAGNETIC RESONANCE IN MEDICINE HIGHLIGHTS

MARK CHIEW

#### 4 ISMRM MEMBERSHIP AT A GLANCE

MARK CHIEW

### COVER STORY

#### 6 MRI IN AUSTRALIA AND NEW ZEALAND

An Informal History of the ISMRM and SMRT in Australia and New Zealand

MARK CHIEW



### RESEARCHER PROFILE

#### 12 ISMRM PRESIDENT LAWRENCE L. WALD

ISMRM's Sustainable Future

MARIA EUGENIA CALIGIURI

### YIA

#### 16 LOOKING BACK: ISMRM'S YOUNG INVESTIGATOR AWARD WINNERS FROM 1995

MARK CHIEW

#### 18 2020 ISMRM YOUNG INVESTIGATOR AWARD FINALISTS

NOAM SHEMESH

### Q&A | EDITOR'S PICKS

#### 24 FUYIXUE WANG & KAWIN SETSOMPOP

Echo Planar Time-resolved Imaging (EPTI)

INTERVIEW BY KRISHNA NAYAK

TRANSCRIPTION BY JANA HUTTER

#### 26 CAROLE LAZARUS, ALEXANDRE VIGNAUD & PHILIPPE CIUCIU

SPARKLING: k-space filling curves

INTERVIEW BY MATHIEU BOUDREA

TRANSCRIPTION BY MARK CHIEW

#### 28 XING LU, SAEED JERBAN & JIANG DU

3D ultrashort TE imaging for human cortical bone

INTERVIEW BY NIKOLA STIKOV

TRANSCRIPTION BY MARK CHIEW

**30 RUSSELL LAGORE & KÂMIL UĞURBIL**

Brain imaging at 7 Tesla with a 64-channel receive array

INTERVIEW BY AGÂH KARAKUZU  
TRANSCRIPTION BY SOPHIE SCHAUMAN

**32 XIAOXIAO ZHANG AND XIN ZHOU**

Free-base porphyrins as CEST MRI contrast agents

INTERVIEW BY MATHIEU BOUDREAU  
TRANSCRIPTION BY PUNEET BAGGA

**34 ALIREZA VALI & SUSANNE SCHNELL**

Semi-Automated Analysis of 4D Flow MRI

INTERVIEW BY ATEF BADJI  
TRANSCRIPTION BY JULIO GARCIA FLORES

**36 PHILIPP EHSES & TONY STÖCKER**

Whole-brain B1-mapping using three-dimensional DREAM

INTERVIEW BY NIKOLA STIKOV  
TRANSCRIPTION BY SOPHIE SCHAUMAN

**38 TONIMA S. ALI & KONSTANTIN I. MOMOT**

Mammographic density by single-sided portable NMR

INTERVIEW BY ATEF BADJI  
TRANSCRIPTION BY JULIO GARCIA FLORES

**40 ROBERT CLAESER, MARKUS ZIMMERMANN, & N. JON SHAH**

Sub-millimeter T1 mapping of rapidly relaxing compartments

INTERVIEW BY MATHIEU BOUDREAU  
TRANSCRIPTION BY JANA HUTTER

**42 FILIP SZCZEPANKIEWICZ & MARKUS NILSSON**

Design of gradient waveforms for tensor-valued diffusion encoding

INTERVIEW BY NIKOLA STIKOV  
TRANSCRIPTION BY AMY HOWARD

**44 KAI HERZ & MORITZ ZAISS**

T1 $\rho$ -based dynamic glucose-enhanced (DGE $\rho$ ) MRI

INTERVIEW BY FANG LIU  
TRANSCRIPTION BY PUNEET BAGGA

**46 SEBASTIAN PAPAZOGLU & SIAWOOSH MOHAMMADI**

Biophysically motivated estimation of R2\*

INTERVIEW BY EMILIE MCKINNON  
TRANSCRIPTION BY AMY HOWARD

**48 TOM HILBERT, DAVID NORRIS & TOBIAS KOBER**

Fast model-based T2 mapping using simultaneous multi-slice excitation

INTERVIEW BY PINAR ÖZBAY  
TRANSCRIPTION BY JULIO GARCIA FLORES

**50 LORENZO DI SOPRA, MATTHIAS STUBER, AND JÉRÔME YERLY**

Automated free running 5D whole-heart MRI

INTERVIEW BY JESSICA MCKAY  
TRANSCRIPTION BY MARK CHIEW

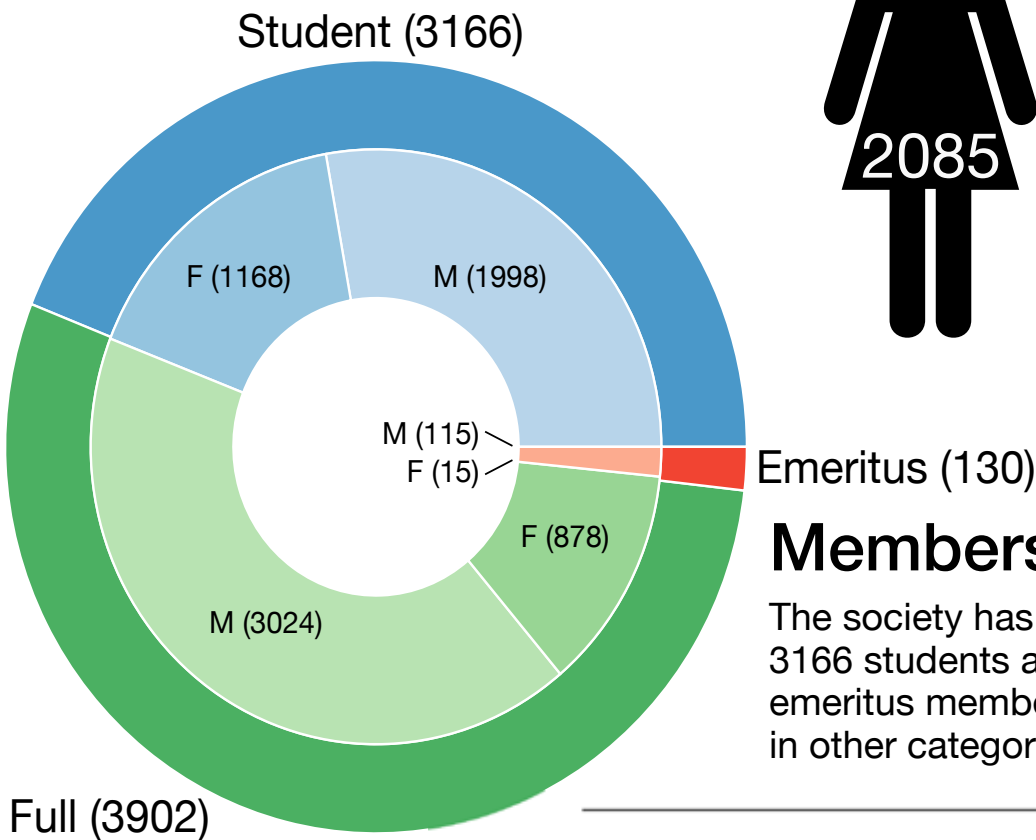
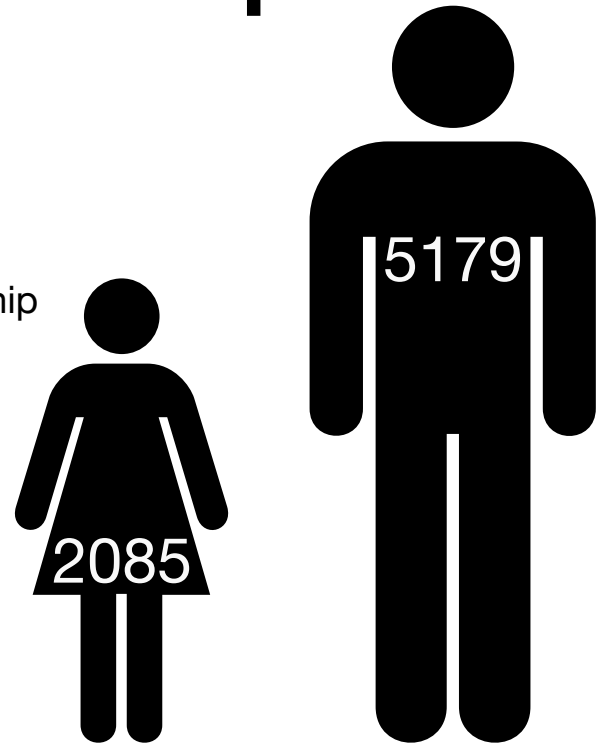
## CONTRIBUTORS

**52 MEET THE TEAM**

# ISMRM Membership At A Glance

## Gender Ratios

Self-reported genders of the society membership come out to about 2.5 men for every woman

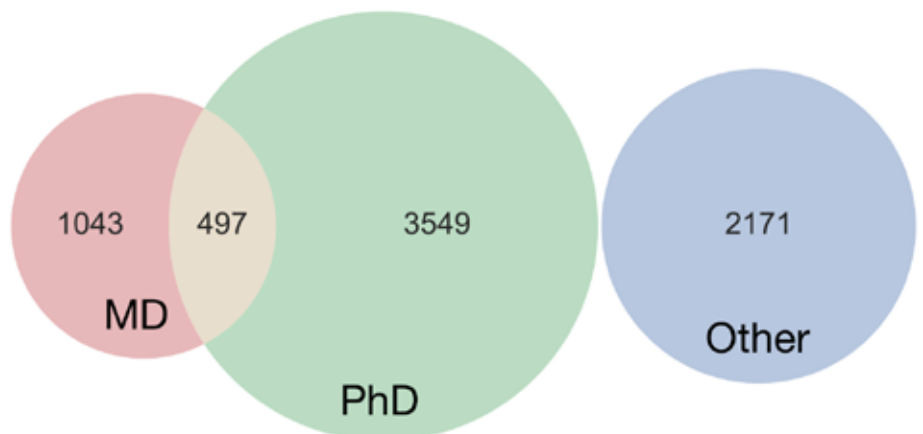


## Membership Types

The society has 3902 full members, 3166 students and trainees, 130 emeritus members, and 66 members in other categories (not shown).

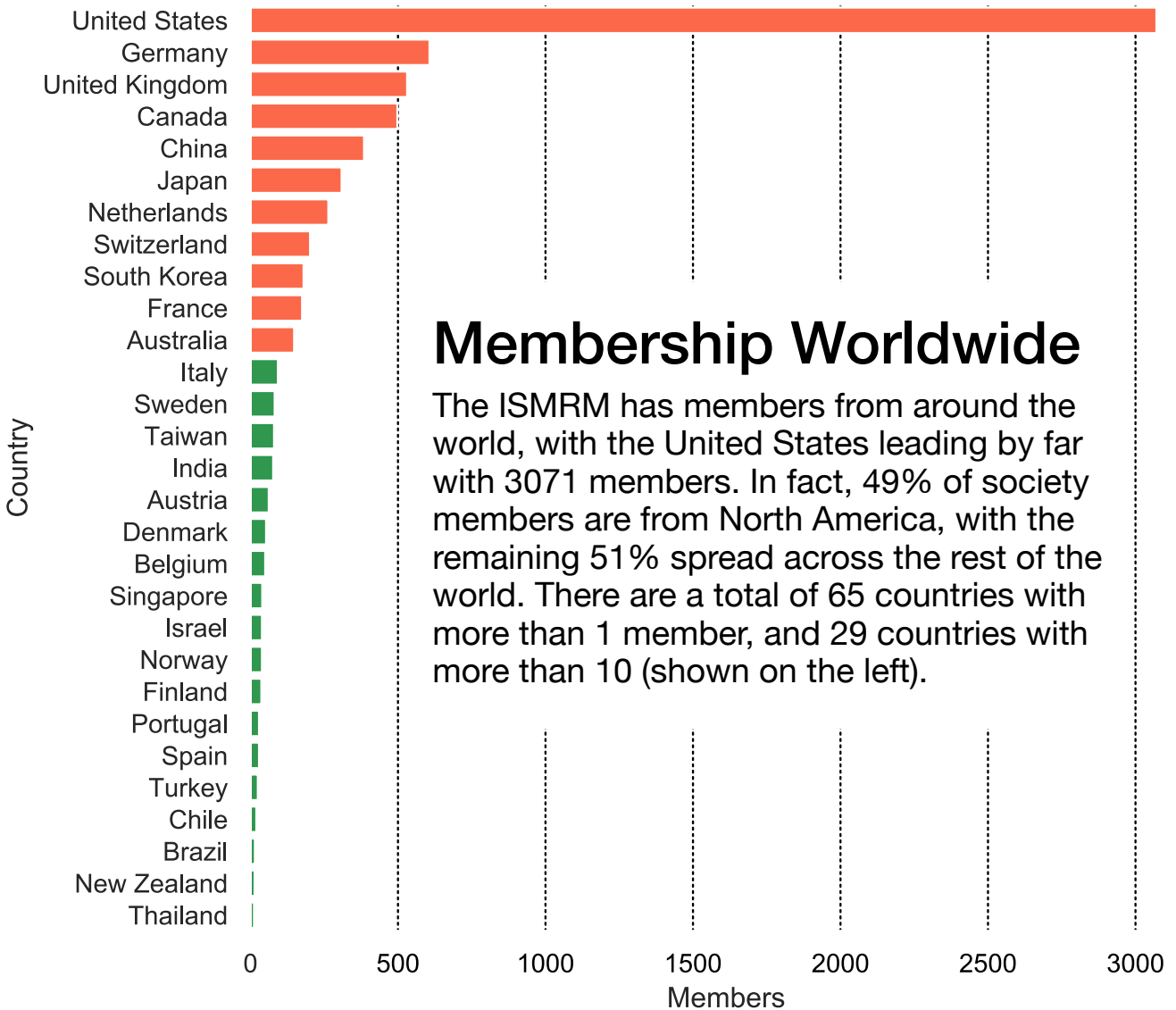
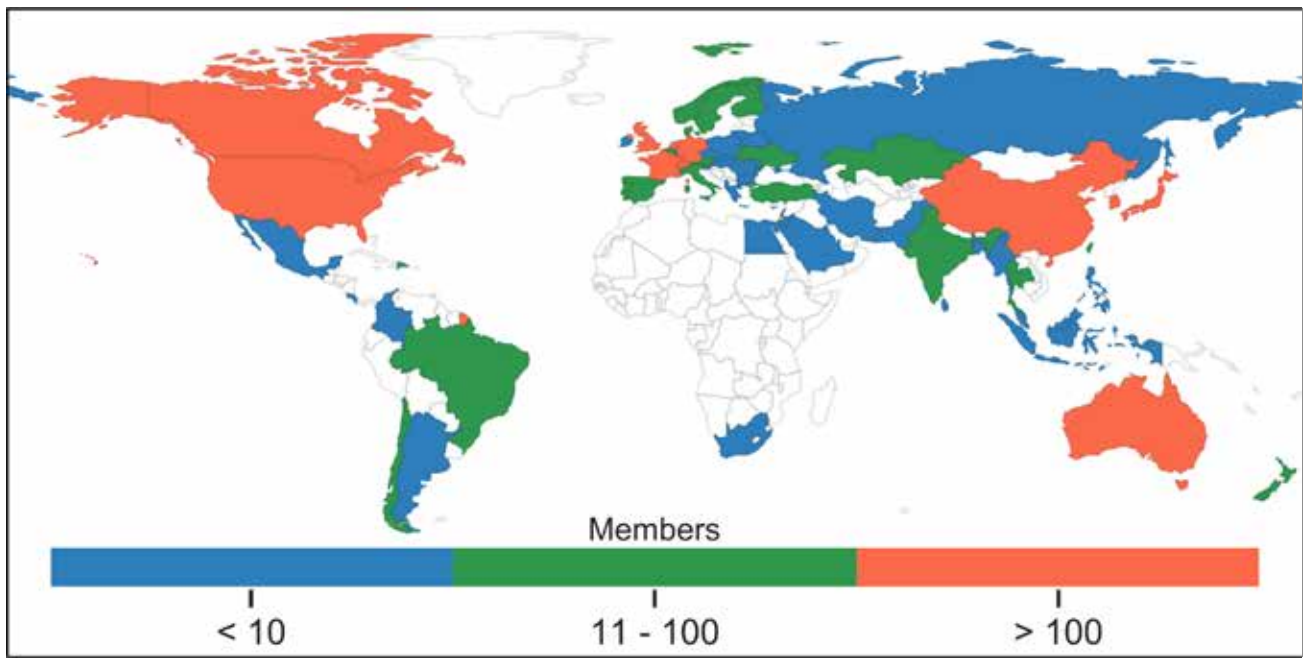
## Degrees\*

1043 members reported having an MD, compared to 3549 having a PhD. Nearly 1/3 of those with an MD also have a PhD (497).



\*Note that 2171 members have un-reported or other degrees, which are not included in this breakdown.





## Membership Worldwide

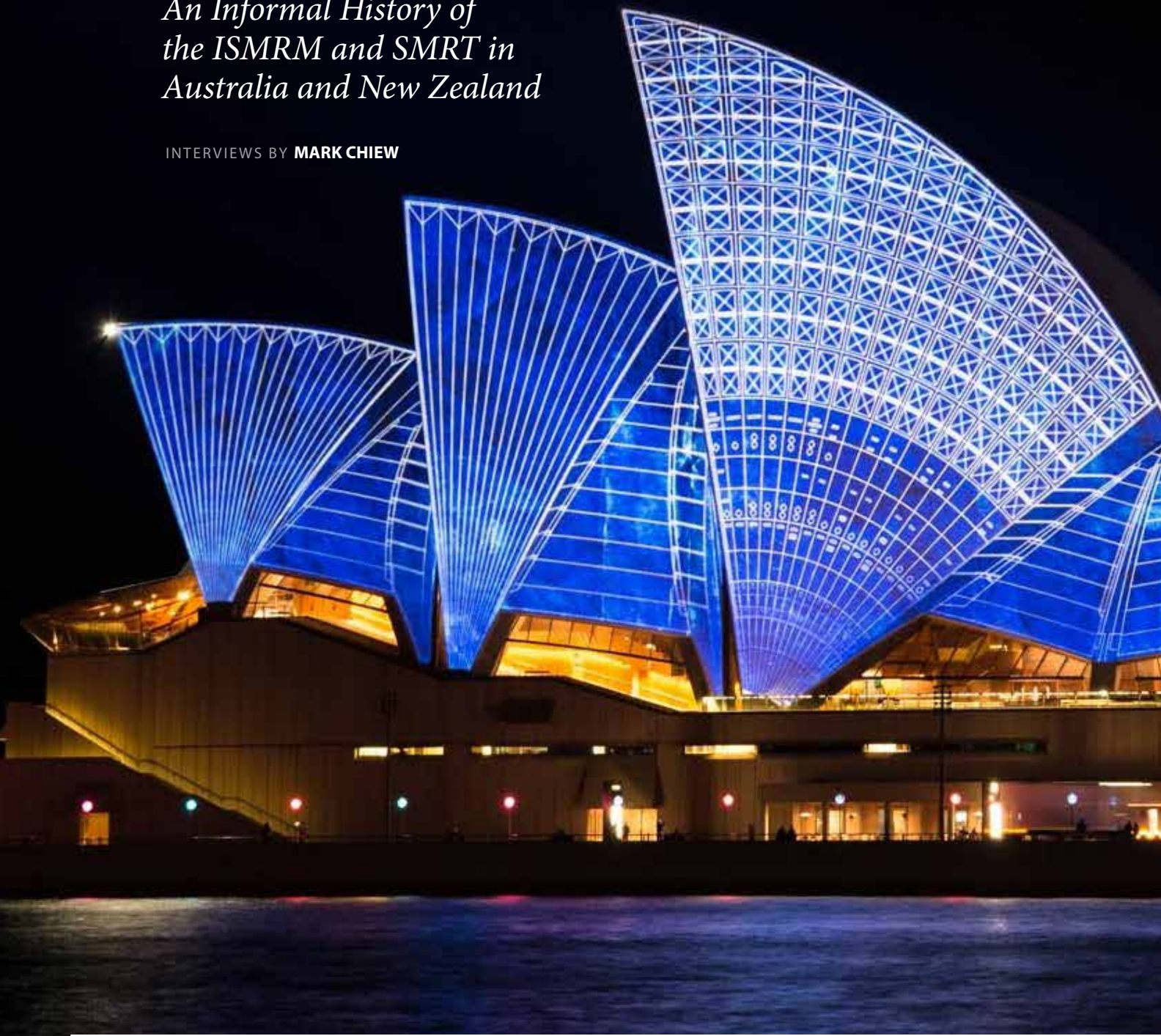
The ISMRM has members from around the world, with the United States leading by far with 3071 members. In fact, 49% of society members are from North America, with the remaining 51% spread across the rest of the world. There are a total of 65 countries with more than 1 member, and 29 countries with more than 10 (shown on the left).

COVER STORY

# MRI in Australia and New Zealand

*An Informal History of  
the ISMRM and SMRT in  
Australia and New Zealand*

INTERVIEWS BY **MARK CHIEW**





**T**his year, the ISMRM's 28th annual meeting will be held in Sydney, Australia, which marks only the third time the meeting has been located in the southern hemisphere - the previous times being Melbourne in 2012 and Sydney in 1998. Some interesting facts about this 1998 meeting:

- There were 2916 abstracts submitted, an increase of nearly 10% from the previous year's meeting in Vancouver.
- Nearly 15,000 abstract copies had to be sorted and physically mailed to 229 different reviewers!
- For this meeting, 24.5% of abstracts were not accepted, 50.6% were posters, 3.7% were poster walking tours, 2.8% clinical focus sessions, and 18.5% oral scientific sessions.
- Poster walking tours took place each day during the poster sessions - a tour of a selected group of posters was conducted by a moderator, with the authors of each poster providing a four-minute overview of their

poster, followed by a discussion period.

- Scientific meeting registration cost \$475 for members, \$650 for non-members, \$90 for trainee members, and \$120 for trainee non-members.
- Attendees had the chance to enter their names in a drawing for a free ISMRM membership for the 1999 calendar year by submitting completed meeting evaluation forms.

To provide some insight into the history of MR imaging and spectroscopy research through the lens of these previous Australian meetings, we spoke with some of the people involved in their construction:

- Carolyn Mountford, Chair of the Pan-Pacific Organizing Committee for the Sydney 1998 Meeting.
- Chris Boesch, Chair of the Annual Meeting Scientific Program Committee for the Sydney 1998 Meeting.
- Graeme Jackson, Chair of the Local Organizing Committee for the Melbourne 2012 Meeting

**MRM Highlights: Can you tell us a bit about the construction of the 1998 Sydney meeting?**

**Carolyn:** We were asked to hold the 1998 meeting in Sydney in 1994 by then President Bob Balaban, which gave us 4 years to prepare and raise supporting funds. The 1998 meeting was the first in the Pan Pacific region and the first in the Southern Hemisphere. There was a Pan Pacific Committee created with senior scientists and radiologists from Australia, India, Singapore, Japan, Malaysia and New Zealand. China advised as to how they could best attend. Thus 1998 was the Society's first truly international meeting.

**MRMH: What were some highlights from the 1998 meeting in Sydney?**

**Chris:** I remember very well the opening lecture given by Paul Callaghan - this was definitely a highlight. Paul Callaghan embedded his own NMR experiments of ice in Antarctica (he brought his NMR system to the ice which he measured in situ!) in a philosophical context about the human drive to discover



The Sydney Opera House



**Past ISMRM President Debiao Li at the 2012 Melbourne ISMRM annual meeting**

the unknown. He talked about a historical exhibition with dozens of fatal casualties “just” to find the egg of a king penguin and went from this story onto philosophical thoughts about the curiosity and thirst for knowledge that makes us human. One particularly memorable fact: while the evaluation sheets from the attendees were 99% extremely positive, one attendee wrote “I could not learn anything for my daily practice...”.

**Carolyn:** Shackleton’s book was sold out in Sydney within 12 hours of Paul’s Lecture.

**MRMH:** How about highlights from the 2012 meeting in Melbourne?

**Graeme:** One of my best memories from the 2012 meeting is that Paul Bottomley gave a fantastic lecture on history and how things happened in MR. Paul was one of those Australian’s who has a fantastic career, and hearing him talk about how things evolved in his keynote lecture was just a real highlight.

**MRMH:** Any other stand-out memories or anecdotes from either of these meetings?

**Carolyn:** The opening event was in the Op-

era House and sponsored by Toshiba, and it included the traditional Japanese sake ritual. In addition to Australia’s best performers the late Bill Hull, a brilliant pianist and a member of the society, also performed.

**Chris:** It was a great feeling to stand on the stage of such a famous place (the Opera House). I knew that during the ceremony, a traditional didgeridoo would be played. Since I had heard a didgeridoo performance in an almost dark, 1250 year old church several months before the ISMRM meeting, I suggested that this didgeridoo performance also be in the dark. They played it before a night sky and the performance and scene was really breath-taking.

Also, as far as I remember, we designed a new abstract form which could be printed in a laser printer. Before that, a very large abstract form required that several parts were glued onto the form.

**Graeme:** I think everyone has a memory of the closing party at the Sydney meeting. Carolyn put forth a huge effort, and was quite determined,

and as I remember, managed to get GE to sponsor the party. There was an Australian theme there, music, and good food - a very memorable, and probably one of the most memorable parties from any ISMRM. Nowadays, you have one ticket for alcohol or something like that, but I think back then it was a bit more generous. Just one of those really lovely nights.

**Carolyn:** The closing event was a South East Asian market with stalls from all participating regions. The party sponsored by GE was so good that they left the bar open for an extra few hours. There were a few sore heads the next day...

**MRMH:** The meeting has returned to Sydney after 22 years. A lot has changed in the world since then - how do you feel the society has changed in this period?

**Chris:** Independent of the specific meeting in Sydney, the different fields in MR changed dramatically: almost every year, we had new, fascinating fields popping up and the diversity within MR got immense. Just as an example and without exact numbers: in Syd-



ney, spectroscopy contributed a considerable part of the abstracts; today, spectroscopy is just one field amongst many others. I think this “every-year-a-new-field” is exactly what makes MR (and thus ISMRM) so unique - MR continues to grow and develop from one Annual Meeting to the next.

**Graeme:** The meeting itself always felt big, you know. There were a lot of people, and a lot going on. I don't know if this was deliberate, but it went from “how do you build the equipment so this stuff actually works” to very much a lot of clinical development where people were discovering all these clinical applications with decent imaging. Then, in recent years, it feels like it has swung back towards technical development, so I suspect these things have some natural cycles to them according to what advances are being made.

**Carolyn:** The educational aspects of the society are to be proud of and allow the youngsters from all backgrounds to learn. The increasing role of SMRT, started by Cruse and Kressel has had a big impact worldwide on the quality of MR data in the clinic and in research settings. Here, Australia has taken a lead internationally as can be seen by the current and past presidents of SMRT. However, there is no longer any serious input from the local committees. I think this is a

shame and would like to see this reinstated. The local committees created good will and understanding that extended far beyond the realms of the ISMRM. It allowed trust to be built up between leaders of countries around the world in science and medicine. This is perhaps one of the greatest contributions of our Society that has gone unrecognised.

**MRMH: Conversely, how have things changed in Australia?**

**Carolyn:** Balaban's insight gave MR a new life in our region of the world. At the time the only clinical research scanner in Australia was a GE 1.5T in Sydney. The 1998 meeting stimulated the Pan Pacific region and MR was embraced as both a research and clinical tool. Today Australia has a National Imaging Facility which is well funded by the Federal Government and ensures cutting edge capability is readily available.

**Graeme:** Well, when I first started imaging research, I worked with a 0.3 T scanner at the Royal Melbourne Hospital! But after I came back to Australia following my time in London, I did try to get people interested here, but the University hospital wouldn't provide scanner access because they didn't want to waste that time on research. The said, “Graeme, you're a neurologist - if you want to do re-

search in Australia, you should do clinical research that doesn't involve expensive things.” I really felt, coming back to Australia, that the idea that we could use high technology like they did overseas was just not Australia. So the only option was to get a group together and form a new research institute that eventually got the first 3 T scanner, a GE Horizon in 1999, for the express purpose of having a high field MRI in Australia. I'm not sure exactly what changed, but I think things like getting the scanner in '99, and having things like the ISMRM come to Australia had an effect, and now there are research dedicated scanners all over the country, including a 7 T at the University of Melbourne. Consequently, Australia is now probably as well positioned as anywhere in the world to do this next stage of imaging research.

. . .

We also had the great pleasure of speaking to Shawna Farquharson, current President of the SMRT, about the history and growth of the Australia and New Zealand (ANZ) chapters of the ISMRM and SMRT.

**MRMH: Can you tell us a bit about the origins of the ANZ SMRT Chapter?**

**Shawna:** Looking back, one of the most im-

**Professor Roger Ordidge at the controls of the 7T MRI system at the University of Melbourne. Photo courtesy of the Australian National Imaging Facility.**



portant events for the Australia and New Zealand (ANZ) MR Community was the establishment of the ANZ SMRT Chapter in 1995 by Greg Brown and Mike Kean. Greg and Mike had both been privileged to attend international meetings of the Society of Magnetic Resonance in Medicine (SMRM) and the Society of Magnetic Resonance Imaging (SMRI), which later merged to form what we now know as the ISMRM. They were so inspired by the MR education program and the inclusivity of the multi-disciplinary environment, that they teamed up and embarked on a mission to bring world-class education to ANZ. At the time there were only a handful of MR scanners in ANZ. Although Greg & Mike could see how big MRI would be in the future they had to start small, so small that I am told by Greg “that he only needed to buy 5 stamps to post the first ANZ MR User group newsletter”, however, the ANZ community soon went from strength to strength.

**MRMH: How has the ANZ SMRT Chapter grown since then?**

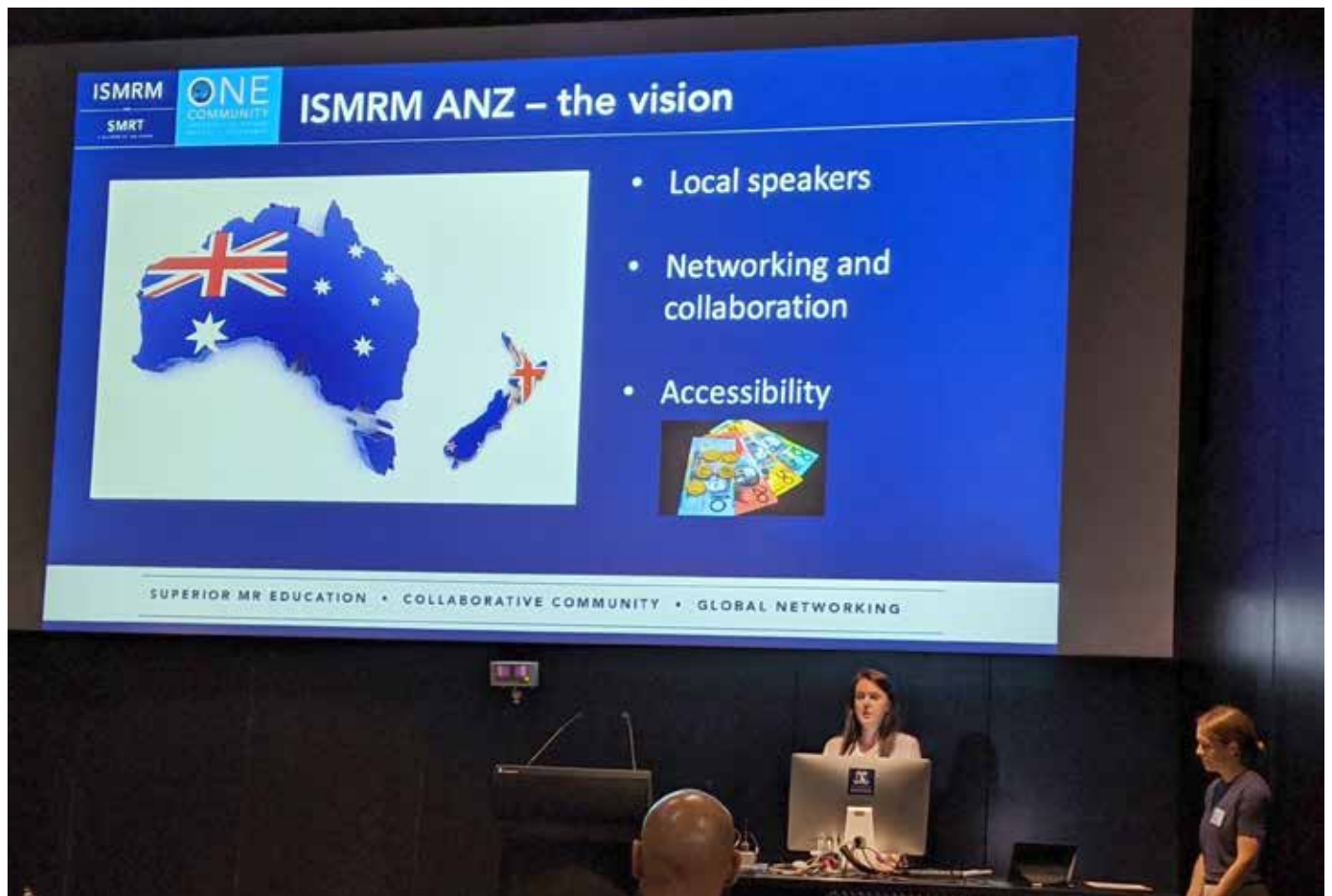
**Shawna:** In the mid 2000s the ANZ leadership team led by Wendy Strugnell (international SMRT Past-President & former SMRT ANZ Chapter President) helped take the ANZ SMRT Chapter ‘to the next level’. In 2006 they established the first of a series of Annual National Chapter meetings hosted across Australia & New Zealand to complement the international ISMRM/SMRT program. As many in region had never been in a position to attend an international MR-focused meeting this was a really important initiative. It brought internationally renowned scientists, clinicians, radiographers and technologists to the region such as Mike Moseley, Miki Lustig, Dan Sodickson, Maureen Ainslie, Anne Sawyer, Cindy Comeau, Lale Umutlu, Harriet Theony, Stefan Sunear, Alexander Leemans, Rhys Slough, Christine Chung, Jan Casselman (to name just a few), and also impor-



**2019-2020 SMRT President - Shawna Farquharson**

tantly provided a platform for local radiographers and technologists to present their research in the same forum. I still remember to this day receiving an oral presentation for my very first abstract. It was such an honor to be presenting at the ANZ National meeting in Melbourne. Although I have to confess

**Ruth Oliver (ANZ ISMRM National Chapter President) giving the opening speech at the inaugural ANZ ISMRM Chapter meeting hosted at the Florey Institute in Melbourne, December 2019. Photo courtesy of Shawna Farquharson.**





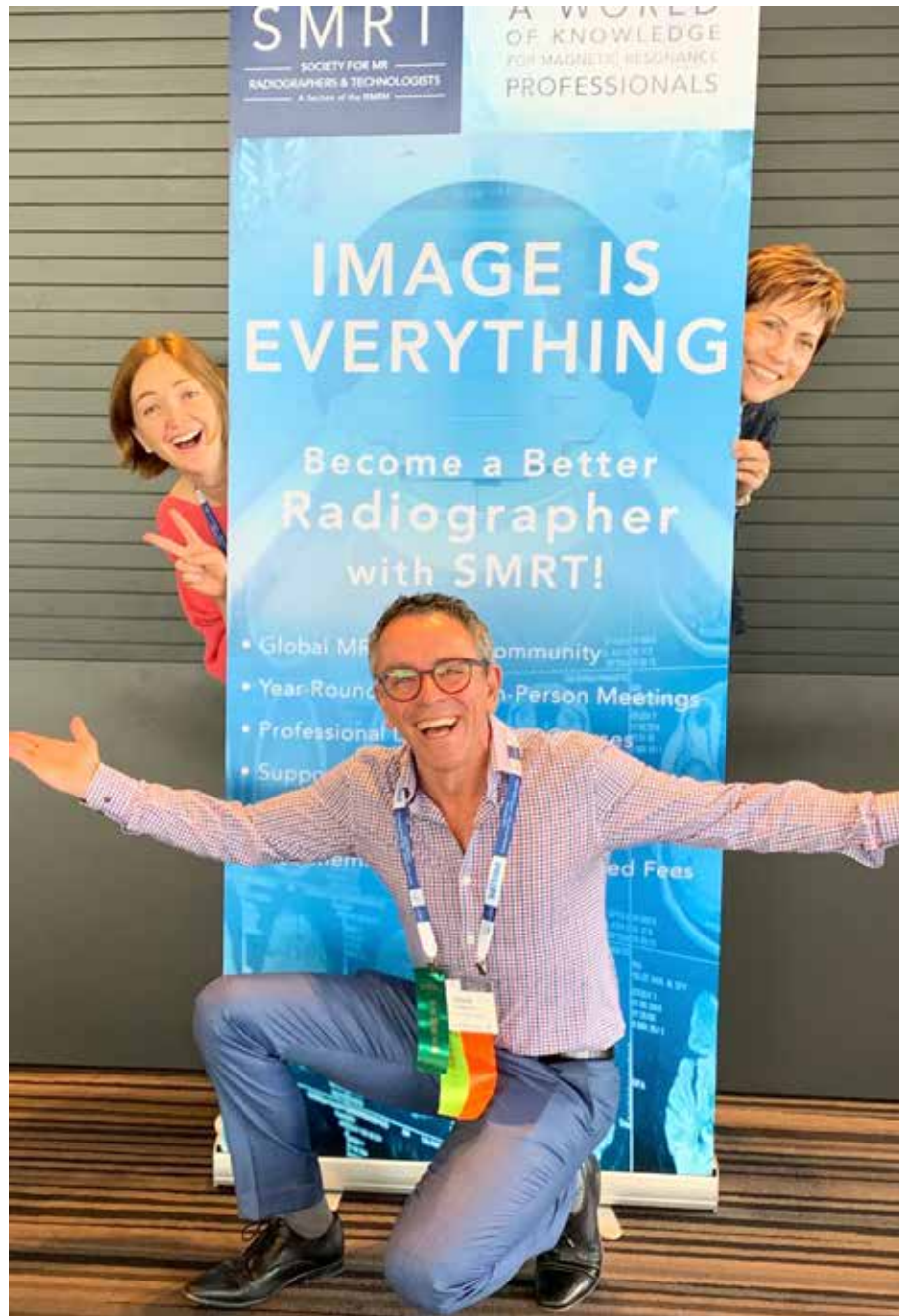
at the time I was terrified of public speaking and that it was only the support and encouragement of my former boss Prof. Alan Connolly that got me through the ten minute talk that felt like a lifetime. Alan still jokes that he actually attended the SMRT Melbourne meeting just in case I passed out - so he could finish the talk on my behalf!

**MRMH: Where do you see the Chapter heading in the future?**

**Shawna:** Each year the SMRT Annual National Chapter meeting attracts hundreds of attendees from across ANZ and more recently the Asia Pacific MR community. Over the past decade the ANZ SMRT Board has also been extremely proactive in developing and providing a framework to support its future MR leaders and educators, which is why I believe there have been so many exceptional MR leaders from the ANZ region who have served as international SMRT Policy Board members and SMRT Presidents. The ANZ SMRT Board is now the midst of a grassroots campaign to establish ANZ SMRT Divisions to support local MR communities in each state. These key initiatives have helped the ANZ SMRT Chapter evolve from its relatively humble beginnings to become one of the most successful and sustainable Chapters within our community.

**MRMH: You're also involved with the new ANZ ISMRM chapter - can you tell us a bit more about that?**

**Shawna:** As current SMRT President, and the current secretary of the newly formed ANZ ISMRM National Chapter, I am absolutely delighted to see our ANZ MR community (once again) go from strength to strength. This past year the ANZ scientific community came together to help officially petition for the formalization of the ANZ ISMRM Chapter. Just months after receiving approval, the ANZ Chapter led by Ruth Oliver (ANZ ISMRM Chapter President), hosted the inaugural ANZ ISMRM Chapter meeting in Melbourne. It was an extremely successful meeting that was well attended by scientists, clinicians, vendors, radiographers & technologists. The focus of the 1st ISMRM Chapter meeting was to celebrate the wide range of MR research in ANZ 'from MR development to its clinical application', and throughout the event the program featured exceptional presentations from students, early career researchers and 'ISMRM legends' from across



**Chris Kokkinos (SMRT Past-President, front), Claire Mulcahy (SMRT Policy Board, left) and Wendy Strugnell (SMRT Past-President, right) showing 'true leadership' and getting involved in the social media competition held at the 2019 ANZ SMRT Annual Meeting to promote the importance of being a member of the SMRT. Photo courtesy of Shawna Farquharson.**

the region. Watch this space, as plans for the next meeting to be hosted in Queensland are already underway. The ANZ ISMRM Chapter is also embarking on a number of initiatives to help connect and promote the scientific community across ANZ and potentially the Asia-Pacific region. From my perspective, it is wonderful to see both the ISMRM and

SMRT communities working together to help create a cohesive, collaborative & supportive environment for MR professionals throughout the region. The success of these Chapters will directly benefit our international ISMRM & SMRT membership, and provide the support and framework to help develop our future leaders. ■

# ISMRM's Sustainable Future

INTERVIEW BY MARIA EUGENIA CALIGIURI

Lawrence L. Wald is Professor of Radiology at Harvard Medical School and Director of the NMR Core in A.A. Martinos Center at Massachusetts General Hospital (MGH). This past year he has also been our ISMRM president. In this interview, he shared with us memories from his early ISMRM meetings, as well as his views on a broad variety of topics, from work-life balance to environmental sustainability.

**MRM Highlights:** When was your first ISMRM meeting? And how many of these meetings have you been to since?

**Larry Wald:** My first annual meeting was the 1993 meeting in New York, when the society had a different name (Society of Magnetic Resonance in Medicine). Since then, I have attended the annual meeting every year, making the next one my 28th.

**MRMH:** What were your early ISMRM meetings like? Did you recognize many people?

**LW:** Everything was new to me back then; I was a post-doc at University of California San Francisco, and only knew the people attending from my Lab. It felt intimidating, but that's the point of international meetings: getting to know new people. I always advise my young collabora-

tors to hang-out with people that they don't see every day, i.e. go to lunch with a "stranger" to broaden their circle of acquaintances outside of their home institution.

**MRMH:** How did you get started with MRI research in the first place?

**LW:** As an undergraduate in early '80s, I first heard about MRI research on one of the early clinical scanners, but unfortunately my fellow student explained it so badly that it provoked no interest. But years after, when I had the chance to properly study the technique, I fell in love with MR. I think it's the perfect playground for research in medical imaging. Its theory is simple enough that you can fully understand it, but rich enough to give rise to a nearly infinite number of phenomena and interesting interactions with the physical and biological world.

**MRMH:** Do you remember your first ISMRM presentation?

**LW:** It was in 1994, the Annual Meeting was held in San Francisco. I was a post-doc working on MR spectroscopy at that time, and I remember hoping to go "unnoticed", since at that time there could be a much more "vigorous" debate on the technical details of presentations. In the end it went pretty well. The director of a lab to which I had applied as post-doc (and had been rejected!) was in the audience and it got back to me that he thought my images were "pretty good"... so I thought "this went well!"

**MRMH:** What were your first steps in ISMRM on the path that ultimately lead you to become this year's President?

**LW:** I very rarely turned down a role or opportunity to give a talk (much to my wife's disapproval!). I remember that I began getting involved with the Society by reviewing abstracts for the Annual Meetings. Then I started giving educational talks, which I really enjoyed doing, and I also moderated some scientific sessions. Basically, you get others to notice you, remember your face and name by initially doing small – but still important – things; and then bigger things come. Soon, I was involved in some study groups and committees. Study

Lawrence Wald and his family: wife Julie, daughter Chloe and dog Charlie.





groups provide an optimal environment to talk about a specific scientific topic and have low barriers to creating new initiatives. Committees, such as the Annual Meeting Program Committee, can be demanding, but it has been satisfying to take part and contribute to important aspects of the society.

**MRMH: Has ISMRM changed over the years?**

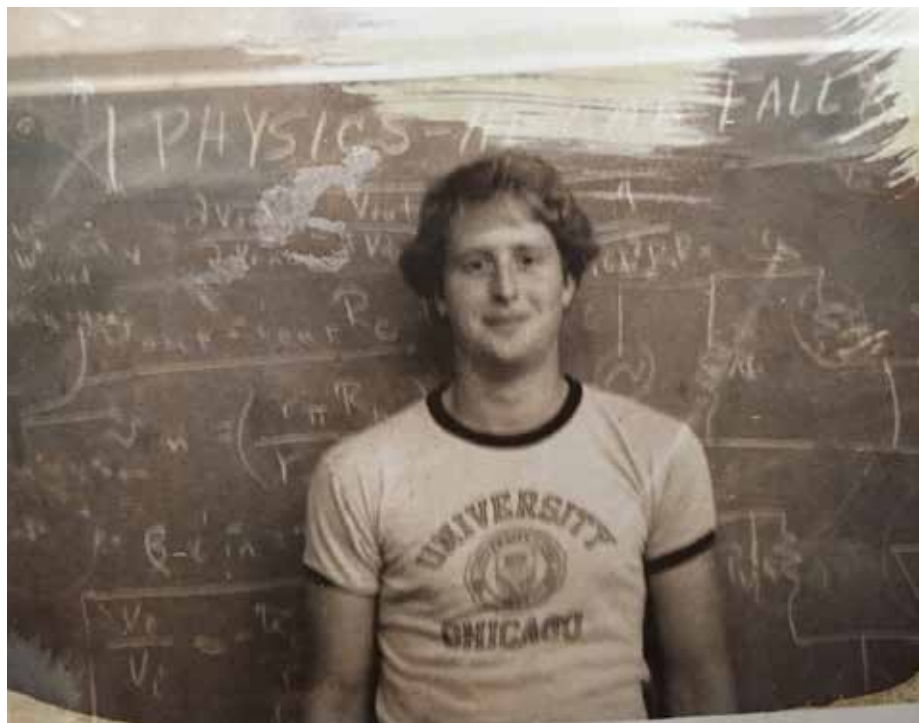
**LW:** Overall, I think it has been evolving scientifically. Ours is a technology that is constantly re-inventing itself and morphing into new applications and applying new technologies. These technical advances are at the heart of the Society - its aim to use these to bridge MR physicists and clinicians - has stayed the same.

**MRMH: ISMRM has been very committed to equality, diversity and inclusion (EDI) among its members. What do you think are the results of these efforts? Is there anything else that would be worth doing in this regard?**

**LW:** Yes, the Society has taken several concrete steps toward ensuring an environment where everyone is welcome and encouraged. One recent step to codify this has been the introduction of an Equity Diversity and Inclusivity (EDI) Officer on the Board of Trustees and Exec. Committee, as well as an EDI ad hoc committee. Both are doing a great job at overseeing this and introducing new initiatives. Unfortunately, EDI comes with a lot of thorny problems that we, as a Society, will keep addressing, but also extend outside our Society's structure. One of these is managing a successful career while also achieving a work-life balance. This is something that we all face every day - it is a truly "inclusive" issue, though it often presents a more significant barrier for women than men. I am heartened by the fact that it is being discussed more, and that the idea that you have to renounce family life and solely focus on science to succeed is fading away. But I do think that academic structures have been slow to adjust.

**MRMH: Thinking about the future, are there any specific novel advances in the field in which you think would be worth investing in?**

**LW:** It is hard to tell which emerging technique will eventually become recognized worldwide as a new standard in MRI. Back in the old days, I remember image reconstruction with anything but the FFT being looked at "with suspicion." Something like introducing prior knowledge in image reconstruction was considered heresy. Indeed, with the advent parallel imaging and then compressive sensing, the clear benefits finally overwhelmed these hesitations. Now, of course, AI is worming its way into everything. I don't think we will blindly turn the problem over to AI/ML, but use methods like neural nets as just another tool in our optimization/modeling tool box. I look forward to the day that all of the mutual information in our image series can be exploited. That we don't reconstruct



a T2 image without considering how the data from the preceding T1 image can help. But overall, I think that biological insight will never be devalued, and that future important MR developments will always leverage both biology and physics. I also hope that we will look

**Lawrence Wald in 1982, when he was a graduate student teaching assistant at Berkeley. The photo at the blackboard was taken with a polaroid camera meant to capture oscilloscope traces (yes, this was before digital scopes!)**



**Lawrence Wald**



**Lawrence Wald at one of the benches in his Lab**

back and wonder why we always needed an image to answer our radiographic questions. Maybe a 1D depth profile of T2 and diffusion from a cheap hand-held device will suffice...

**MRMH:** Recently, MRM published an editorial by Nikola Stikov et al., entitled “Reproducibility and the future of MRI research”, highlighting the importance of promoting reproducible research to address replication issues and foster translation of innovative methods into clinical practice. What is your opinion on open science and research transparency in our field? Are there any initiatives of this kind that you are interested in?

**LW:** Its definitely critical to promote reproducibility and transparency in our field. I am heartened by the increased effort to share open source tools so that everyone doesn't have to reinvent everything; both software and hardware. This is crucial to lower the barriers that prevent others from trying and validating a method and ultimately will speed up its translation into clinical practice.

**MRMH:** This year, ISMRM has launched Sustainability Initiatives to reduce the environmental impact of the meeting (<https://www.ismrm.org/20m/sustainability/>). What do you think we can do, as individuals, to contribute facing the climate crisis?

**LW:** We have to understand that there is a “new” cost associated with how we've been doing things, either

in our everyday life or when organizing and attending large scientific meetings. I am optimistic that sustainability can be achieved, although I admit we have a long way to go. I view the first steps like an economist. Currently, when it comes to considering the “carbon cost”, the best tool we have are the various carbon offset calculators that estimate the cost of any travel (which are used in ISMRM's sustainability initiatives). Carbon offsets and the mitigation project they fund are imprecise and not perfect, but are a first attempt to try to include the environmental cost. I encourage you to look into these offsets, and weigh the cost of mitigating the carbon emission of any travel you take into the cost-benefit equation for that trip. We will also be ramping up virtual offerings and meetings. Hopefully with our first full-scale virtual Workshop soon (there have already been numerous virtual study section meetings). These will be important learning steps for us before we can think about virtualizing the annual meeting.

**MRMH:** Do you have any tips for young investigators or PhD students that are just starting in the MR community?

**LW:** Yes, I really want them to know this: your presentation reaches farther than you think. Even if your first poster lays in a sea of other posters that seem to be getting more interest, even if you are giving your first talk in front of a half-full room, remember that your contribution will be online for years, and many other people (me included) will see it from their labs or homes. And while I loved the efficiency of browsing paper posters, I view the potential archiving of digital posters as a real win. One of my goals as president is to try to make all of our content easier to find on-line and have more reach.

**MRMH:** How do you see young people contributing to the society? Do you have any particular suggestion to get junior researchers and clinicians involved in the society?

**LW:** Trainees and early career researchers represent a large percentage of our members and generate almost all of the content. It is crucial to continue to encourage their participation by introducing dedicated activities that advance their careers. Hopefully there will be an expanding number of opportunities for them to get involved. Workshops and study sections are a great entry point for members to apply his/her interest and form new initiatives that can grow from there, even helping to organize a future workshop. Start becoming active soon, the ISMRM is always looking for energetic people!

**MRMH:** What are you looking forward to at this year's ISMRM annual meeting?

**LW:** I am looking forward to the weekend after the meeting, when I will be studying the wave-sand interaction with my feet on the beach! ■



An aerial photograph of a winding asphalt road that curves through a dense, green forest. Several cars are visible on the road, including a red car at the top, a blue car, and a white car. The text is overlaid on the image.

**Don't miss reaching your  
target audience...**

**Secure your ad  
placement for the  
2021 Highlight  
Magazine Today!**

**Contact Beverly Lawrence at  
[BLawrence@Wiley.com](mailto:BLawrence@Wiley.com) for more information.**

**WILEY**



# Looking Back: ISMRM's Young Investigator Award Winners from 1995

“When I first went to ISMRM, I realized that this was my home, and these are my people”  
-Garry Gold

Heather R. Cross, DPhil won the 1995 I.I. Rabi Young Investigator Award for her paper entitled *The Role of Na<sup>+</sup>/K<sup>+</sup> ATPase Activity During Low Flow Ischemia in Preventing Myocardial Injury: A <sup>31</sup>P, <sup>23</sup>Na and <sup>87</sup>Rb NMR Spectroscopic Study*

After receiving her DPhil in biochemistry from the University of Oxford, Heather went on to work as a visiting fellow at the NIEHS studying sex differences associated with recovery from ischemic injury in mice. She then moved to Duke University Medical Center, where she is now the director of the clinical operations centre for an NIH-funded program studying antibacterial resistance ([www.arlg.org](http://www.arlg.org)).

Garry E. Gold, MD won the 1995 W.S. Moore Young Investigator Award for his paper entitled *MR Imaging of Collagen: Tendons and Knee Menisci*

Upon completion of his clinical training, Garry was appointed to Stanford's Department of Radiology, where he has been ever since. As a past president of the ISMRM (2016), we managed to catch up with Garry and asked him to describe his experiences surrounding the 1995 annual meeting in Nice, France, and reflect upon the past 25 years.

## MRM Highlights: How did you get into MRI and musculoskeletal imaging?

**Garry:** I started working on ultra-short TE imaging in the late 1980s with John Pauly, Al Macovski and Bob Herfkens while I was going to medical school at Stanford. Originally, I was working on a project looking at atherosclerotic plaque in the aorta, but having taken anatomy in medical school, and after talking with people at various meetings, I realized that a large part of the musculoskeletal system, particularly ligaments, tendons and menisci all fit under this class of ultra-short T2 tissues. Then, after having spent so much time during my residency studying the knee, it was a natural fit for me to go on clinically and specialize in musculoskeletal imaging.

## MRMH: Take us back to 1995 - can you describe what it was like for you to win the Young Investigator Award?

**Garry:** I have several fond memories from that whole experience. It was really transformative for me, to become part of the ISMRM, apply for and be selected as a finalist, and ultimately be selected to win the Moore award. I was a resident in Radiology at Stanford at the time, and the '95 meeting in Nice was my first international conference, and my first scientific presentation outside of the US. A little bit scary, frankly, to get thrown into the deep end for your first talk to be a young investigator talk, and I do remember practicing and practicing. I

also remember spending many nights scrambling to try and get a particular image of the ultra-short T2 signal from the knee, which involved trying to play a 32 ms RF pulse on an amplifier that would only accept pulse lengths up to the 16 ms...

**MRMH:** I think just about everyone who has ever submitted an ISMRM abstract has experienced some late night desperation. Please go on...

**Garry:** Well at the time we were using a long RF pulse that John had developed to perform long T2 suppression. One night I had this idea that maybe I could get a better imaging by lengthening the pulse and narrowing the bandwidth - so I put this into the code and I tried this out on one of our clinical scanners at Stanford. It was late at night, probably around midnight, and trying to run the sequence resulted in a loud “PING” and a message on the scanner that said “radiofrequency amplifier resetting”. My first thought was, of course, that Bob (who was my mentor in the Radiology department and head of MRI) was going to kill me because I've just broken one of the clinical scanners! Luckily, I found out that I didn't damage anything permanently, and it was the consequence of an RF pulse that was too long.

## MRMH: Did winning the Moore award influence your career?

**Garry:** Absolutely. As I continued to work on these tech-



**Members of Stanford's Radiology and Electrical Engineering Departments in 1994. Garry is the 4th from the left, back row.**

niques after winning, and presented at future meetings, both at ISMRM and elsewhere, I received much encouragement from clinicians and clinician scientist colleagues. In particular I remember Michael Recht, who is now Chair of Radiology at NYU, was a moderator at one session I presented at. He said, "I think you should use this technique to really look at the articular cartilage", which was really quite formative for me, because it led to my interest in cartilage imaging, cartilage breakdown and ultimately imaging osteoarthritis. You know, I'm not super old, but at this point in my life, I sometimes think back and realize that these really small interactions have made a huge difference in my life.

**MRMH: In just over 20 years, you went from Young Investigator Award winner in 1995 to ISMRM President in 2016. What makes the ISMRM special to you?**

**Garry:** When I first went to ISMRM, I realized that this was my home, and these are my people. And it was because there were both clinicians and scientists working side-by-side, speaking to each other and moving the field

forward together. It's one of the things that I really appreciate about the society, from the AMPC to the board, to the president, there has always been a focus on maintaining the balance between clinical and scientific content in the meeting. There's somewhat of a natural tension there, and I think we've always had more basic scientists than clinicians or clinical scientists at the meeting, but there's been a terrific recognition from the ISMRM leadership around that and maintaining balance.

**MRMH: Do you have any advice for those students and trainees who are today where you were back in 1995?**

**Garry:** Sure - one piece of advice that I try to give to students is that when you have a meeting like the ISMRM, use the opportunity to get out of your comfort zone and go to some sessions that are maybe outside of your narrow part of the field. Try to learn what's going on in other areas of MRI. I really encourage people to look a little bit outside their box, and let their minds wander and think "what if?" while they're seeing people present their work. ■



**Garry, on the far right, pictured with (starting from the left): Greig Scott, Kim Butts Pauly, Maria Meyer and Craig Meyer.**

# 2020 ISMRM Young Investigator Award Finalists

EDITED BY NOAM SHEMESH

Every year the Society nominates three finalists each for two Young Investigator Awards (YIA), and the winners are announced at the annual meeting. The W.S. Moore Award (JMRI) is given for original clinical research, whereas the I.I. Rabi Award (MRM) is given for original basic science research. This year we have an outstanding group of finalists, and we have the pleasure of showcasing them here in the Highlights magazine.

## Cheng-Chieh Cheng

### *I.I. Rabi YIA Finalist*

Cheng-Chieh obtained his Ph.D. from the Graduate Institute of Biomedical Electronics and Bioinformatics, at the National Taiwan University. He studied under the supervision of Dr. Hsiao-Wen Chung, who inspired and encouraged Cheng-Chieh to pursue the path of MRI research. He then performed his post-doctoral research work with Dr. Bruno Madore in the Advanced Lab for MRI and Acoustics (ALMA), in the Radiology Department at the Brigham and Women's Hospital, Harvard Medical School. This work included

novel MRI pulse sequences and quantitative MRI methods, as well as the development of MRI-compatible ultrasound-based motion monitoring systems. In 2019, he joined the group of Dr. Felix Wehrli in the Laboratory of Structural, Physiological and Functional Imaging (LSPFI) at the University of Pennsylvania to work on blood T2 quantification and MRI-based quantification of oxygen consumption rate. Most recently, in 2020, he joined the Department of Computer Science and Engineering at the National Sun Yat-sen University in Taiwan

as faculty member.

Cheng-Chieh's expertise centers on MRI pulse sequence development and quantitative imaging methods, and it is combined with a passion for tinkering, soldering and building. His creativity can be glimpsed from the 3D-printed components he created, as needed for example for the development of ultrasound-based 'organ configuration motion' (OCM) sensors and of MR-compatible motion phantoms. His MRI sequence-programming work includes RF pulse design, pathway signal acquisition, motion reduction techniques and image acceleration.

### NOMINATED PAPER:

**“Multi-pathway multi-echo acquisition and contrast translation to generate a variety of quantitative and qualitative image contrasts”**

One way to increase the diagnostic value of MRI is to reduce the length of MRI scans. The need to perform several distinct scans, each one providing a given tissue contrast, is the main reason for long scans. For example, an ideal neuro acquisition may include various T1-weighted, T2-weighted and diffusion-weighted contrast types, along with quantitative maps of basic MR parameters (T1, T2, T2\*, susceptibility, etc.), with good resolution and full-brain 3D coverage. However, in practice, tradeoffs exist between the number of contrasts/maps, the spatial resolution, coverage, and overall scan time.

We developed a 3D multi-pathway multi-echo (MPME) pulse sequence able to capture vast amounts of information about the imaged object fairly rapidly, although not necessarily with image contrasts that radiologists would be comfortable reading. We trained a neural network (NN) to act as a 'contrast translator' to convert information obtained from the

Cheng-Chieh Cheng





same MPME scan into common qualitative contrasts as well as quantitative maps. In this study, 3D whole-brain MPME scans with clinically-relevant resolution (1.2 mm isotropic) were performed on eight healthy subjects on a 3.0T system in  $6.8 \pm 0.5$  minutes, and commonly-read qualitative contrasts (T1-weighted, T2-weighted, PD-weighted, MPRAGE, and FLAIR) as well as quantitative maps (T1, T2, and B0) were generated through NN-based contrast translation. Because all of these contrasts/maps originate from the same MPME scan, they are essentially in perfect spatial alignment, which simplifies any pixel-based multi-contrast analysis. Our results suggest that the main bulk of a neuro exam could be abbreviated into a single MPME scan, with contrast translation. The current scans were minimally accelerated, and as such scan time could be further reduced below the current 7-min value, and/or resolution could be improved beyond the current 1.2 mm in the future, hopefully boosting the efficiency of routine neuro exams.

## Victor Han

### *I.I. Rabi YIA Finalist*

Victor Han is currently a third-year PhD student in the Department of Electrical Engineering and Computer Sciences (EECS) at the University of California, Berkeley. He is advised by Professor Chunlei Liu. Mainly interested in developing new imaging techniques with custom-built hardware, he would like to develop methods that deviate from standard practice that hopefully push the boundaries of what is possible in dramatic ways. One research area that he is currently particularly interested in is that of portable, very low field scanners.

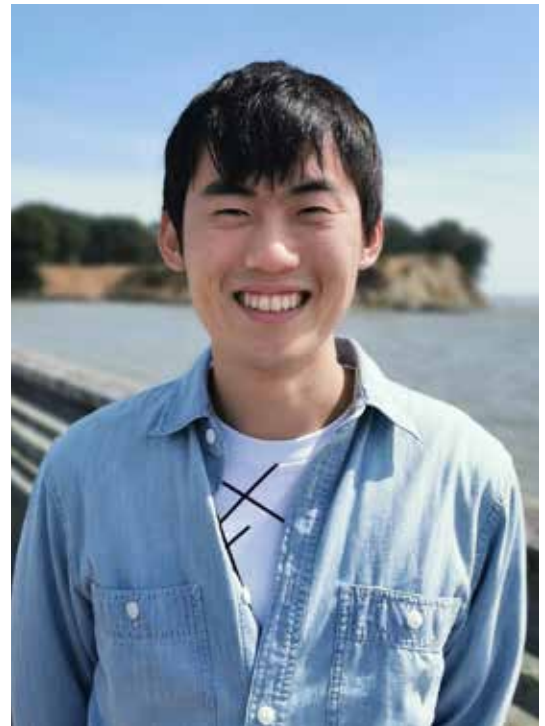
Growing up in San Diego, a hub for biotech work in California, Victor was exposed to biology research early on in high school. In his undergraduate years at the California Institute of Technology (Caltech), Victor was lured by the prospect of controlling nature and studied electrical engineering and computer science. During his summers in college, he worked on optical metamaterials research in Professor Harry Atwater's lab at Caltech, power electronics device modeling at the Mitsubishi Advanced Technology R&D Center in Amagasaki, Japan, and deep learning accelerator development at the IBM Watson Research Center in Yorktown Heights, New York. Thinking that he would continue to work on digital circuits, he entered the PhD program at the University of California, Berkeley in 2017. In his first semester, however, he took a class taught by Professor Chunlei Liu entitled "Advanced Brain Imaging Methods." After being amazed by how MRI can noninvasively image at depth with so many possible contrast mechanisms and no ionizing

radiation, he joined Chunlei's lab. In the future, Victor hopes that his imaging methods will enable us to better understand what goes on within ourselves.

### NOMINATED PAPER:

#### "Multiphoton Magnetic Resonance Imaging"

In our work, we describe an alternative form of excitation useable in MRI. Instead of the usual single-photon resonance, we can excite multiphoton resonances to generate signal for MRI by using multiple magnetic field frequencies, none of which is near the Larmor frequency. Only the total energy absorbed by a spin must correspond to the Larmor frequency. For example, if we have a RF field in the xy-plane at 100 kHz below the Larmor frequency, then normally we do not expect excitation. However, the addition of a RF field along the z-axis at 100 kHz actually generates excitation as a photon from the xy-plane is absorbed together with a photon along the z-axis for a total frequency equal to the Larmor frequency. This basic phenomenon has been described in the NMR and EPR literature as well as by Brunner et al. in a series of ISMRM abstracts. In our work, we expand on a classical Bloch equation model to show that in a particular rotating frame of reference, a multiphoton resonance looks just like a single photon resonance. As a result of this, various concepts that are used in single-photon excitation, such as slice-selective excitation, the Bloch-Siegert shift, and adiabatic pulses, readily generalize to the multiphoton case. Multiphoton effects can be produced either with extra z-axis RF coils or by oscillating the gradients in a standard MRI scanner, as the gradients' magnetic fields are also in the z-direction. We show that with an extra coil, all single-photon excitations in a standard pulse sequence can be replaced with two-photon counterparts, and without any extra hardware, a single band adiabatic pulse may be transformed into a multiband one with the proper choice of oscillating gradients. In the future, by replacing single photon pulses with properly chosen multiphoton pulses, we hope that new contrasts may be



Victor Han

found. As gradient and traditional RF coils gain more channels and spatial-temporal flexibility, we expect that much more can be achieved using multiphoton MRI to encode spatial, spectral, and temporal information.

## Adam van Niekerk

### *I.I. Rabi YIA Finalist*

With a childhood that involved being attached to a giant helium balloon and leaping over the gum trees at the back of our property for one of my dad's work projects, I was probably destined to be "attracted" to something helium related. I started my postgraduate career at the University of Cape Town (in South Africa) as an electro-mechanical engineer with an interest in

biomedical engineering but without a plan for a research topic. I was drawn to MRI by the seemingly magical combination of medicine, physics and engineering to make a camera that can view you from any angle without any moving parts. Although, strictly speaking, that isn't entirely true. The camera is often used to image something living, which can probably be defined as a moving part. This moving part is a problem.

With some experience in inertial measurement using accelerometers, angular rate sensors and magnetometers (sensors commonly found

in a cellphone to help you read the text the right way up) I decided to try and tackle this problem. After all, how hard could it be? I had been relying on the Earth's magnetic field as a reference in an action-camera stabilization project and was excited to attempt to apply this same logic to the MRI scanner's static magnetic field.

I have been working on this problem ever since...

Fortunately, my novel approach allowed me to upgrade my original masters project to a PhD which was awarded to me by the University of Cape Town in early 2019. After multiple prototypes I managed to come up with a form of intelligent marker that combines vector measurements of both the time varying and stationary magnetic fields in the MRI scanner to determine sub-

ject pose. I am currently doing a postdoctorate at the Karolinska Institutet, where I am working on developing these devices to behave as hardware extensions for the pulse sequence programmer to manipulate.

### **NOMINATED PAPER:**

### **"Toward 'plug and play' prospective motion correction for MRI by combining observations of the time varying gradient and static vector fields."**

This paper explores the efficacy of our Wireless Radiofrequency-triggered Acquisition Device (WRAD – with a silent "W" like write or wrong) for prospective motion correction in a 3D pulse sequence. The WRAD is a small intelligent marker that can be attached to the patient to monitor their movement.

So how does it work?

The WRAD first detects a specific RF pulse in the pulse sequence. We treat these RF pulses as synchronization events. This is equivalent to a sync pulse used in a task-based fMRI study, except that for the WRAD we wanted to eliminate cables and didn't want to add any additional hardware.

Secondly, the WRAD uses this time frame synchronization to sample a set of 3 orthogonal pickup coils during a series of sinusoidal pulses on each of the gradient coils. The sinusoidal pulses can be thought of as a short navigator lasting a total of 880  $\mu$ s.

Finally, we interpret these pickup coil voltages to find the patient's pose. This is probably the most challenging part of this work. The pickup coils are mostly stimulated by the changing gradients, but unlike an imaging/NMR experiment, which is mostly sensitive to the amplitude of gradient fields in the direction of the static magnetic field ( $B_0$ ), the pickup coils also detect the so-called Maxwell terms perpendicular to  $B_0$ . These are what cause the concomitant field. Fortunately, they have a mostly linear spatial derivative and are relatively straightforward to measure if you have knowledge of the direction of the static magnetic field which we have instant access to thanks to a 3-axis magnetometer!

This gives the WRAD the ability to measure z displacement with the "Maxwell" part of x gradient field and other odd things. We hope this work is a step toward accessible and easy to use ("plug and play") prospective motion correction, relevant to a clinical setting where it is needed most.

## Maria Aristova

### *W.S. Moore YIA Finalist*

Maria Aristova is a PhD candidate advised by Dr. Michael Markl in the department of Biomedical En-



**Adam van Niekerk**

engineering at Northwestern University. She completed a B.S.E. in Chemical and Biological Engineering at Princeton University and worked as a research technician at the Martinos Center for Biomedical Imaging before joining the Medical Scientist Training Program at Northwestern. Her doctoral work is supported by an individual NIH F30 NRSA grant.

Maria's current research interests are in 4D Flow MRI imaging for assessment of the neurovasculature. Mentored by Dr. Susanne Schnell and Dr. Mark, she has focused her doctoral work on developing an appropriate imaging pipeline for fast and accurate neurovascular 4D Flow MRI, from sequence development, image acquisition and reconstruction to image analysis and application to clinical questions.

Maria's sequence development work has focused on the acceleration of dual-velocity encoded 4D Flow for increased clinical applicability. She has also investigated optimization of acquisition parameters in order to identify an imaging protocol that optimally balances acquisition time and flow quantification. Finally, she has worked to identify a generalizable and concise format for communicating and analyzing neurovascular 4D flow MRI data, with the goal of creating a standardized data communication paradigm that facilitates the computation of clinically meaningful imaging biomarkers.

Maria's primary application of interest has been the quantitative evaluation of intracranial arteriovenous malformations, due to the unusual technical requirements (high spatial and temporal resolution, high velocity dynamic range, and low scan time) and lack of quantitative flow metrics in clinical decision-making. Maria's work has also found application in imaging other pathologies, including Vein of Galen malformations and intracranial aneurysms. In the future, she hopes to continue to unite clinical needs and technical advancements in MRI.

#### **NOMINATED PAPER:**

### **“Standardized Evaluation of Cerebral Arteriovenous Malformations using Flow Distribution Network Graphs and Dual-venC 4D Flow MRI”**

Brain arteriovenous malformations (AVMs) are an abnormal connection between arteries and veins. Imaging AVMs may require volumetric coverage of the entire brain and a large velocity dynamic range in small vessels. These challenges can be addressed with dual-velocity encoding sensitivity (dual-venC) and advanced acceleration methods, such as PEAK-GRAPPA. The goal of this paper was to work toward a standardized 4D Flow MRI protocol specialized toward assessment of brain AVM by answering the questions: what parameters lead to the fastest protocol enabling

accurate flow quantification? How can hemodynamic data be presented in a concise way that accounts for anatomical variability? And finally, can quantitative flow biomarkers be identified to describe the hemodynamics of brain AVMs?

To answer these questions, we investigated dual-venC 4D Flow with PEAK-GRAPPA acceleration in vitro and in vivo at 3T. In vitro experiments using a specialized flow phantom were used to assess the limitations of the scan time/image quality tradeoff. By varying the spatial resolution and PEAK-GRAPPA acceleration factor, we assessed quantification accuracy via direct comparison to measured flow. We were able to confirm that 4-5 voxels across the flow channel or vessel is typically sufficient for flow quantification even at high acceleration. We also introduced the Flow Distribution Network Graph (FDNG), a data storage and communication paradigm where the neurovasculature is represented as a directed graph whose weights are hemodynamic parameters such as flow, peak velocity or pulsatility index. We first applied the FDNG concept to investigating hemodynamic differences among anatomic variant groups in our cohort of 26 healthy subjects. We then used the FDNG to extend the concept of pulsatility index analysis to multiple connected vessels, and to identify a quantitative biomarker that can be computed for any AVM regardless of individual anatomy. We demonstrated that FDNG-based biomarkers distinguished vessels connected to the AVM nidus from healthy vessels in the same patient and from the vessels of healthy controls. The potential impact of this work is the development of a quantitative, generalizable biomarker that can summarize hemodynamic contributions to AVM treatment planning. Future directions include investigation in an expanded AVM cohort for further validation and correlation with treatment outcomes.

### **Kelly Jarvis**

*W.S. Moore YIA Finalist*

My contributions to MRI started in 2004 as a re-



**Maria Aristova**





**Kelly Jarvis**

search assistant in the Department of Psychiatry and Behavioral Neuroscience at the University of Cincinnati. I contributed to multiple projects and published my own study evaluating brain morphometry in bipolar adolescents with and without cannabis use disorders.

Wanting to become a research scientist, I started my PhD in Biomedical Engineering at Northwestern University in 2011. As a student with Dr. Michael Markl, expert in MR physics and cardiovascular imaging, my research focused on developing 4D flow MRI methods to

characterize blood flow in the heart and large thoracic vessels in patients with congenital heart disease.

As a postdoctoral fellow in Dr. Markl's lab in the Department of Radiology at Northwestern University since 2017, my research focuses on the investigation of aortic hemodynamics using 4D flow MRI. My developments include 1) analysis tools for the automatic quantification of aortic pulse wave velocity in patients with cryptogenic stroke and 2) quantitative maps for the evaluation of true and false lumen flow characteristics (reverse flow, stasis, kinetic energy) in aortic dissection.

Over the years, I have worked on a number of studies (>60 abstracts: 20 as first author, 29 publications: 5 as first author). I was awarded a 2-year American Heart Association (AHA) predoctoral fellowship and a 2-year postdoctoral National Institutes of Health, National Heart, Lung and Blood Institute (NIH, NHLBI) T32 fellowship through the Northwestern Molecular and Translational Cardiovascular Training Program.

I have presented my work at scientific conferences (AHA, ISMRM, Society for Cardiovascular Magnetic Resonance (SCMR), Society for Magnetic Resonance Angiography (SMRA)) and outreach events (Northwestern Science in Society, Graduate Women in Science). I have received awards such as Best Basic Science Paper (Pediatric Radiology 2016), Junior Investigator Award (AHA International Stroke Conference 2018), Best of the Moderated E-posters finalist (SCMR 2019, 2020) and magna cum laude (ISMRM 2015, 2019).

Being selected as a finalist for the Young Investigator Award is a great honor and I thank the ISMRM organizers. I am forever grateful to my mentors and colleagues. I would like to thank my primary mentor, Dr. Markl, for his expert guidance and support. Thanks also to organizations that have provided my grant funding (AHA, NIH, NHLBI) and opportunities to speak and interact with the scientific community (AHA, ISMRM, SCMR, SMRA).

#### **NOMINATED PAPER:**

### **“Parametric Hemodynamic 4D flow MRI maps for the Characterization of Chronic Thoracic Descending Aortic Dissection”**

Aortic dissection is a life-threatening vascular disease that occurs when blood flows through entry tears in the intima of the native aorta, or true lumen (TL), generating a false lumen (FL).

Descending aortic dissection (DAD) can be isolated (Stanford type-B) or associated with ascending aortic dissection (Stanford type-A). Treatment planning for DAD is complex with most patients managed medically at first.

One of the main questions in chronic DAD is which patients should have thoracic endovascular repair (TEVAR) to prevent complications such as aortic rupture and visceral malperfusion. We hypothesized that comprehensive evaluation of aortic hemodynamics can help improve our understanding of DAD and the classification of patients.

The main motivation of our study was that systematic evaluation of complex flow in chronic DAD is needed to better understand which patients are predisposed to false lumen thrombosis or dissecting aneurysm. Our goal was to develop 4D flow MRI-derived hemodynamic maps for characterization of the TL and FL.

4D flow MRI was acquired in 20 DAD patients (age=60±11 years). This included 6 medically managed type-B aortic dissection (TBAD) as well as 14 repaired type-A aortic dissection (rTAAD) with ascending aortic graft or elephant trunk repair. Also included were 21 age-matched controls (age=59±10 years).

Preprocessing of the 4D flow MRI data included 3D segmentation of TL and FL volumes. 4D flow MRI analysis tools were developed to evaluate the voxel-wise calculation of forward flow, reverse flow, flow stasis, and kinetic energy. These data were visualized as mean intensity projections and displayed as quantitative hemodynamic maps.

Results showed that 4D flow MRI-derived quantitative maps demonstrated global and regional hemodynamic differences between DAD patients and controls—patients with rTAAD had elevated TL reverse flow and TL kinetic energy. Also, patients with rTAAD



versus medically managed TBAD had significantly altered regional TL and FL aortic hemodynamics—patients with rTAAD had higher TL and FL kinetic energy and lower FL stasis.

This study demonstrates the utility of 4D flow MRI-derived hemodynamic mapping as a quantitative technique for the characterization of chronic DAD. These results indicate the potential for parametric mapping of underlying TL and FL hemodynamics to play an important role in the understanding of aortic dissection.

## Thierry Lefebvre

### W.S. Moore YIA Finalist

I am a highly motivated French-Canadian Master's student in medical physics studying cancer and liver disease imaging at McGill University in Montreal. Interdisciplinary research, scientific communication, and outreach are the main fields of interest in which I try to devote most of my time. My current research is focused on extracting quantitative biomarkers from MR images by taking advantage of MRI's numerous tissue contrast mechanisms. By studying clinical imaging, I aim to develop tools to better assess diseases through noninvasive 3D visualization of pathological processes.

In 2018, I graduated from my bachelor's degree in physics at the Université de Montréal where I was first exposed to clinical research. Three years ago, I undertook a summer internship in MRI and ultrasound imaging of liver disease in Dr. An Tang's laboratory (and remained a close collaborator with his team ever since). Surrounded by clinician-researchers, I became passionate about clinical applications of technological advances in MRI, while consolidating my methodological and computational skills over the years. Through collaborations with MRI physicists, radiologists, hepatologists, pathologists, and statisticians, I gathered tools and valuable expertise needed to conduct clinically relevant research and to tackle graduate studies. As a token of appreciation for all these academic opportunities, I volunteered with the Diversity Physics Committee at Université de Montréal, to promote the role of minorities in science. I also presented in seminars intended to deconstruct scientist stereotypes and recently co-organized the 2019 Women in Physics Canada Conference and McGill's "What is Medical Physics?" Seminar. I hope that these activities had a positive impact on students from diverse backgrounds so that they feel confident to pursue scientific studies. Over the next few years, I aim to expand my scientific collaborations with clinicians and fundamental researchers to develop multimodal and MR-based diagnostic techniques to improve lives of

patients through quality and longevity.

### NOMINATED PAPER:

#### "MRI Cine-Tagging of Cardiac-Induced Motion for Noninvasive Staging of Liver Fibrosis"

Liver fibrosis is the only pathological feature common to all chronic liver diseases. Hence, accurate noninvasive tools are required to assess its stage and progression. Currently, clinically available elastography techniques measuring stiffness provide high diagnostic performance for the staging of liver fibrosis and are indicated

for patients with suspected liver disease. The MR-based implementation, MR elastography, requires external hardware to produce mechanical waves and mainly assesses the right liver lobe. As fibrosis is an intrinsically heterogeneous condition, providing a complete overview of its deposition across the organ could provide prognostic value. Hence, we explored the effect of cardiac motion on left liver lobe strain to assess fibrosis in a cohort of patients also undergoing MR elastography. MRI cine-tagging of cardiac-induced motion uses a preparation sequence to spatially modulate the magnetization resulting in "tags" across images. The deformation of these tags in the liver due to cardiac motion can be tracked over time using phase information to evaluate strain. In a cohort of subjects with chronic liver disease, we reported strain values obtained in a region close to the heart in the left lobe and evaluated their diagnostic performance for staging liver fibrosis, using biopsy as the reference standard. The characteristic increase in stiffness due to collagen deposition in fibrosis was also observed in the reported strain values. Since strain can be understood as the "opposite" of stiffness, cardiac-induced liver strain decreased with increasing fibrosis stage. Similarly to MR elastography, we leveraged the mechanical properties of the liver to determine the disease stage and we found a diagnostic accuracy similar or slightly lower accuracy than that reported for MR elastography. These results suggest that adding this sequence to screening liver MRI examinations could increase our ability to diagnose fibrosis and its distribution across the whole liver. ■



Thierry Lefebvre

# Echo Planar Time-resolved Imaging (EPTI)

INTERVIEW BY KRISHNA NAYAK, TRANSCRIPTION BY JANA HUTTER

## EDITOR'S PICK FOR JUNE

In this Q&A, Krishna Nayak from USC interviewed Fuyixue Wang and Kawin Setsompop from the Martinos center about their recent paper on Echo-planar time resolved imaging (EPTI). EPTI is an extension of Tilted-CAIPI, encoding data in ky-t space to take advantage of signal correlation along these dimensions.

“I’m pretty excited about obtaining high resolution, high SNR and simultaneous T1, T2 and T2\* quantitative mapping in a very short timeframe”  
 –Fuyixue Wang

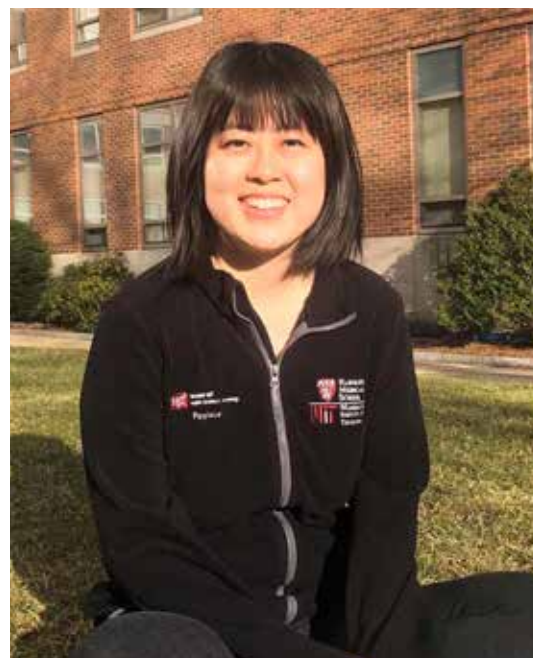
**MRM Highlights:** First of all thanks, congratulations for this great work and also thanks for taking the time to discuss it with us, let me start with some general questions. Can you tell us a little bit about your background. How did you get interested in MRI and how did this project evolve?

**Fuyixue Wang:** I got interested in MRI in college when I was exploring different research fields by taking lab rotations. I was just fascinated by how flexible MRI can be in terms of acquisition, encoding and contrast mechanisms and that also means possibilities to find new information to help with the many medical applications. That’s what got me interested, I applied for graduate school and joined Kawin’s lab where we’ve been working a lot on improving EPI techniques to push the limit of spatial and temporal resolution and acquisition speed.

Two years ago we were working on this other multi-shot technique called tilted CAIPI where we get distortion-free diffusion imaging by using an additional phase-encoding direction. That’s when we realized that, instead of getting the point spread function what if we use a different in-plane strategy and take advantage of spatial temporal correlation across EPI readouts so that we could really look into the information along echo time domain to get time-resolved images with different contrasts.

**MRMH:** I thought the illustrations in your paper and even the figures and your artist slides were exceptionally clear. Do you have any tips for other authors on how to make such clear illustrations?

**Fuyixue:** We’re trying to tell people our technique and there are a few key points that we want to illustrate. So we define the experiments and get the results accord-



Fuyixue Wang

ingly to validate these points. For example, we wanted to show EPTI is able to provide distortion and blurring-free images with multiple contrasts with accurate quantitative measurements. For each of these points we have a separate figure or slide.

**Kawin Setsompop:** It’s a lot of complicated stuff and it was important that she laid it out figure by figure. The key is that each figure tells one point.

**MRMH:** You mentioned some of the history of the project came from you looking at k-t space and so I want to ask you a technical question. The tilted GRAPPA ky-t space appears to be very powerful, can you give some intuition for why this works especially along the t-axis aspect for all these scenarios including gradient and spin-echo?

**Fuyixue:** We were phase-encoding along time, so there will be both phase accumulation and signal decay along time. Phase accumulation due to B0 inhomogeneity can

Wang, F, Dong, Z, Reese, TG, et al. Echo planar time-resolved imaging (EPTI). *Magn Reson Med* 2019; 81: 3599–3615.  
<https://doi.org/10.1002/mrm.27673>  
<https://onlinelibrary.wiley.com/doi/10.1002/mrm.27673>  
<https://blog.ismrm.org/2019/08/16/qa-with-fuyixue-wang-and-kawin-setsompop/>



The team behind EPTI - pictured from left to right: Berkin Bilgic, Jingyuan Chen, Kawin Setsompop, Fuyixue Wang, Zijing Dong, Timothy Reese, Jonathan Polimeni, Mary Katherine Manhard, Lawrence Wald

be well estimated by using coil sensitivity and calibration data. Our GRAPPA kernel was trained to contain these information and we make sure that the kernel is pretty small and along time for several milliseconds so that it will have small  $B_0$  phase accumulation and signal decay that can be well estimated. We are also using complementary sampling along phase encoding direction to take better advantage of the coils.

So in summary it is the complementary sampling, the small time distance and the  $B_0$  information within the kernel that allow us to achieve higher acceleration factors.

**Kawin:** I think she said it pretty well. One point that I would add is about how it goes back to SMASH theory. You are using coil information in SMASH to create harmonics to jump along  $k_x$  or  $k_y$  space. In this case our observation is that the phase evolution is different between the different time points in a short TE. You can use a similar theory on using coil information to estimate that. So once we know that we can jump in these two directions, you can design the trajectory to be complementary in  $k$  and  $t$  to allow to make most use of it.

**MRMH:** I would imagine the performance characterization of sequences like EPTI is a major project. Can you tell us a bit about the tests you performed and if there were any interesting findings?

**Fuyixue:** We've looked into performance under different  $B_0$  levels with different acceleration factors with shot-to-shot  $B_0$  variations as well as SNR and g-factor effects. One analysis that I wanted to highlight here is the temporal correlation and the level of data independence along echoes. We are using the shared information of the neighbouring echo data to reconstruct the target data. This allows us to achieve high acceleration factors but will also result in temporal correlation. We did a Monte Carlo simulation and the correlation was pretty high at first but drops really quickly after only three or four echoes. So there is temporal correlation along echo time as expected but it serves more like a local temporal smoothing with a really short time window and there's

still a sufficient amount of data independency considering that we can get more than hundreds of echoes in each scan.

**Kawin:** I think it's important to do all these characterization with new methods so it doesn't appear like it's just magic. That's part of the issue with this technique, it works so well, that for people to really believe it's working and want to use it we need to run all these simulations and characterizations. I was really happy with the work that she did on these things.

**MRMH:** Can you tell us about applications that you're most excited about?

**Fuyixue:** I'm pretty excited about obtaining high resolution, high SNR and simultaneous T1, T2 and T2\* quantitative mapping in a very short timeframe. We are not only taking advantage of the EPTI read-out but also of the prior information of the low rank signal model and the incoherence that we created using this radial blade sampling. With this approach we already get really good quality data with whole brain coverage at  $0.8 \times 0.8 \times 1.6 \text{ mm}^3$  resolution in just one minute. I'm also excited about the fMRI application using EPTI. We've already shown with preliminary data using gradient echo EPTI in a visual stimulus fMRI experiment that we can get data at  $2 \times 2 \times 3 \text{ mm}^3$  resolution with a 3 s temporal resolution. For each TR we get more than 30 echoes and using the multi-echo data allows to enhance the function of sensitivity, reduce the effects from motion, spin history and physiological noise by measuring the BOLD contrast using T2\* values. It is also distortion-free, great for typical areas with high susceptibility.

**Kawin:** For a normal grad student I would just say focus on one but I'm letting her do all this stuff because I think she can do it. I just want to say one thing about this project. She's a great student to make this work but this is her idea so give her credit for that this technique. She convinced me that we should try this out and this is how the project got started. ■

“I think it's important to do all these characterizations with new methods so it doesn't appear like it's just magic”

–Kawin Setsompop



# SPARKLING: k-space filling curves

INTERVIEW BY MATHIEU BOUDREAU, TRANSCRIPTION BY MARK CHIEW

## EDITOR'S PICK FOR JUNE

In this Q&A, Carole Lazarus, Alexandre Vignaud and Philippe Ciuciu chat to us about their latest MRM paper introducing the SPARKLING method. SPARKLING is an optimization-driven approach for the design of variable density k-space filling sampling trajectories for accelerated imaging.

**MRM Highlights:** Can you give us a brief overview of this work?

**Carole Lazarus:** Our optimization based method that we call SPARKLING, which stands for Spreading Projection Algorithm for Rapid K-space samPLING, was born from a close collaboration between mathematicians, physicists, and engineers working in the French laboratories of NeuroSpin CEA and CNRS. To speed up the acquisition, one strategy is to under-sample the k-space and then use compressed sensing theory to recover the images using non-linear reconstructions. This works well in MRI, but only if the sampling fulfills certain criteria. Indeed, it has been shown that sampling should be distributed along a variable density that is concentrated in low spatial frequencies. Another more general principle for optimal sampling is to have locally uniform coverage, which avoids gaps and clusters of samples that are typical of random sampling. However, these two criteria are difficult to respect in MRI because samples are measured along very regular curves, constrained by gradient amplitude and slew rate. SPARKLING is an algorithm that seeks to minimize the distance between a target density and the generated k-space trajectory, subject to some constraints. The optimization constraints are typically the gradient hardware constraints and echo time, but you also want to control the distance between consecutive samples on a shot. We also use a high sampling rate to maximize sampling efficiency. Our results show that SPARKLING sampling yields the best image quality and seems also more robust to B0 imperfections compared to a spiral scan that suffered from important artifacts. We successfully used it for high resolution 2D MRI, and we actually now have extended to 3D SPARKLING.

“We were surprised at first that these complicated, erratic trajectories were actually performed correctly by our gradient system”

- Carole Lazarus



Carole Lazarus

Lazarus, C, Weiss, P, Chauffert, N, et al. SPARKLING: variable-density k-space filling curves for accelerated T2\*-weighted MRI. *Magn Reson Med*. 2019; 81: 3643–3661.

<https://doi.org/10.1002/mrm.27678>

<https://onlinelibrary.wiley.com/doi/10.1002/mrm.27678>

<https://blog.ismrm.org/2019/07/12/qa-with-carole-lazarus-alexandre-vignaud-and-philippe-ciuciu/>

**MRMH:** Were you surprised by any of the results of this study?

**Carole:** We were, yeah. We were surprised at first that these complicated, erratic trajectories were actually performed correctly by our gradient system. That was one of the first things we checked in this project.

**Philippe Ciuciu:** We met some difficulties, and what was really surprising was the fidelity to which the gradient system reproduced the trajectory Carole designed on her computer. Also, the way the approach could be extended to 3D imaging is a very good, positive surprise,



**Alexandre Vignaud**

even though it is still in ongoing validation.

**Alexandre Vignaud:** Also, we were thinking that maybe at some point we would have peripheral nerve stimulation. Again, surprisingly, it wasn't that bad in this area. Finally, when we started to compare to spirals, which Carole had wanted since the beginning, we had this nice result that we were probably less sensitive to off resonance because of these zig-zag patterns.

**MRMH:** Where do you see the biggest potential impact of this technique?

**Carole:** As we showed in the paper, the SPARKLING algorithm is able to improve the initial sampling patterns when you have the time to move around - so the read-

out duration is really important. So every application that enables us to move around will benefit from the SPARKLING method, and in that sense it is very general, because if your initial sampling pattern is already optimal, it won't change it. It's like a locally optimal solution, and incorporates existing trajectories.

**Philippe:** The application we have in mind for the future, for high impact, especially in the clinic is susceptibility weighted imaging, in 3D, with a target of maybe 600 um isotropic resolution in about one minute, which is not doable right now in clinical routines. And to, for in-



**Philippe Ciuciu**

stance, investigate a disease impacting the microvascular cerebral network, such as CADASIL disease. Also, potential applications for high resolution fMRI, in 3D. But in that case, we need to go to single-shot SPARKLING, which is a little bit more challenging than what we have already implemented in the context of the paper.

**Alexandre:** I would just add that from my point of view, my feeling is that anywhere you are doing radial, we might be able to do better, in any case. And therefore, any new or interesting strategy done with radial, on abdominal or dynamic imaging, we might be successful at.

**MRMH:** Thank you! ■

6

*“The application we have in mind for the future, for high impact, especially in the clinic is susceptibility weighted imaging, in 3D, with a target of maybe 600 um isotropic resolution in about one minute, which is not doable right now in clinical routines”*

- Philippe Ciuciu

9

# 3D ultrashort TE imaging for human cortical bone

INTERVIEW BY NIKOLA STIKOV, TRANSCRIPTION BY MARK CHIEW

## EDITOR'S PICK FOR JULY

“So this study was focused more on feasibility, and while we do want to have clinical applications, we still have some way to go for that”

–Jiang Du

In this Q&A, we continue the exploration of cortical bone microstructure using ultrashort echo time UTE imaging with a 3D cone trajectory. In their latest paper joint first authors Xing Lu and Saeed Jerban applied tricomponent analysis to identify bound water, pore water, and fat fractions demonstrating high specificity to bone mineral density.

**MRM Highlights:** Can you guys tell us a little bit about your background and how you came to work in this area?

**Saeed Jerban:** My background is in Mechanical Engineering - I did my PhD at Sherbrooke University in Canada. I was focused on bone graft and bone imaging using micro CT and CT, and then I got interested in MRI. I contact Jiang in 2016, and since then I've been working with Jiang on validating different MRI techniques, particularly correlating UTE imaging with mechanical and microstructural properties of bone.

**Xing Lu:** It was about 2015, and the Chinese government had a program to support people studying new technologies. At that time, I won a grant, so I came to Jiang's lab and I stayed about 2 years, the second year as a post-doc supported by Jiang. After that, the conditions of my funding meant I had to come back to China.

**MRMH:** Jiang, this seems to be the third time you've been interviewed for Highlights, and it seems like this is a really fruitful field for you. Can you tell us about your groups strong links to China?

**Jiang Du:** We have been working together with GE on this UTE technique, by trying to develop new acquisition techniques to evaluate bone, knee joints, the brain (like myelin), and there are many hospitals in China that are interested in these techniques. So I go back to China to visit these hospitals to install these sequences, and we've got them installed now on more than 40 different sites. So that's how we've got more people working with us, particularly from China.

**MRMH:** Going from two to three components introduces quite a few more free parameters to the fit - do you think the simulations could have been simplified

by reducing the amount of free parameters?

**Xing:** Actually the model could be made more simple because we can use assumptions like treating all the fat peaks as one, which would be much easier on the three-component fitting, but I don't think it will be as good as the multi-peak model. As I've left Jiang's lab, maybe the people who are still there can do some further study of this.

**MRMH:** This work is the first time you've incorporated fat in your analysis - can you tell us a bit about the



Lu, X, Jerban, S, Wan, L, et al. Three-dimensional ultrashort echo time imaging with tricomponent analysis for human cortical bone. *Magn Reson Med*. 2019; 82: 348– 355. <https://doi.org/10.1002/mrm.27718> <https://www.onlinelibrary.wiley.com/doi/10.1002/mrm.27718> <https://blog.ismrm.org/2019/08/09/qa-with-xing-lu-saeed-jerban-and-jiang-du/>





Jiang Du

**significance of this change?**

**Saeed:** In human bone, we have a considerable amount of fat, which is not probably as significant in the bovine bone we used in some of our earlier papers. But if we have fat in cortical bone, there will be contamination of the fat and water signals, which can result in high errors in regions of high fat using older analysis methods.

**MRMH: So how can we speed this up?**

**Jiang:** So this study was focused more on feasibility, and while we do want to have clinical applications, we still have some way to go for that. I think to speed up the acquisition we could consider a number of approaches, for example multi-echo acquisitions.

**MRMH: The code that you used was written in MATLAB, and it's also exciting data that you are acquiring. Is there any chance this data and code could be made available to other researchers that are interested in your work?**

**Jiang:** Yeah definitely. We've been planning to put all the code for our different projects online for the community. Right now our guys are kind of busy, and they want to better optimize the code before they put it up, so that's our plan.

**MRMH: It was very nice to talk to you. Thanks you so much and good luck with your future research. ■**

“Contamination of the fat and water signals can result in high errors in regions of high fat using older analysis methods”  
—Saeed Jerban



The team behind UTE cortical bone imaging

# Brain imaging at 7 Tesla with a 64-channel receive array

INTERVIEW BY AGÂH KARAKUZU, TRANSCRIPTION BY SOPHIE SCHAUMAN

## EDITOR'S PICK FOR JULY

In this Q&A, we discuss the latest paper by Kâmil Uğurbil and Russel Lagore from the University of Minnesota, focused on a 64-channel receive array coil that improves acceleration and SNR at 7 Tesla.



Kâmil Uğurbil



Russell Lagore

**MRM Highlights:** Before proceeding to the technical details, can you tell us a bit about yourselves and how you got involved in MRI?

**Kâmil Uğurbil:** I started doing NMR when I was registered at Columbia University. I did various kinds of spin resonance, NMR for protein structures, and optical detection of triplets, which are electron states in certain molecules. From there, my real involvement in what I do now started when I went to Bell Laboratories after I got my PhD. There I joined a biophysics group, and they were interested in using NMR for studying intracellular biochemical processes in intact systems. That developed into my interest in using magnetic resonance to obtain biological and physiological information in-vivo, and in

humans. That started a chain-reaction leading to everything we have done so far.

**Russell Lagore:** I have been an RF engineer with CMRR for 5 years working with Gregor Adriany in the engineering group. I previously took my masters at the University of Alberta and I was supervised by Nicola De Zanche. We were studying noise figure in the influence of magnetic fields. That's how I got into MRI.

**MRMH:** Now we would like to hear a brief backstory on your paper. How did you get it off the ground and what was the biggest challenge that you faced along the way?

**Kâmil:** The background comes from our interest in pushing high resolution imaging, especially functional imaging. We have always been aware of the limitations of doing high-resolution imaging: the inefficiencies that come in by up-sampling k-space in traditional ways. We emphasize in the paper that there are a lot of synergies between high fields, and a high number of channels. There were no instruments available commercially, where they allowed a high number of receiver channels. One of the things we had to do was the development of the 64-channel receiver on the Siemens 7T platform. When you have so many receiver channels, you have fairly dense coil arrays, Russell can comment on all the challenges that come with that.

**Russell:** You've got smaller loops over the same surface area as you would for a 32-channel coil. You have got a lot more interactions between neighbouring elements, so the geometric decoupling becomes more complicated. You have more sheath currents, which can confuse your measurements, and you're trying to get these decoupled. Your circuitry needs to shrink. Because we used on-coil pre-amps, they needed to be small enough to fit within limited space. There were several iterations of rearranging loops, testing it on the scanner to see if we got the performance, fixing channels that weren't performing up to spec...

**MRMH:** It sounds like you dealt with a lot of practical problems to achieve this. What underpins this success?

**Kâmil:** As I mentioned, there are a lot of synergies between very high fields and arrays with many receive

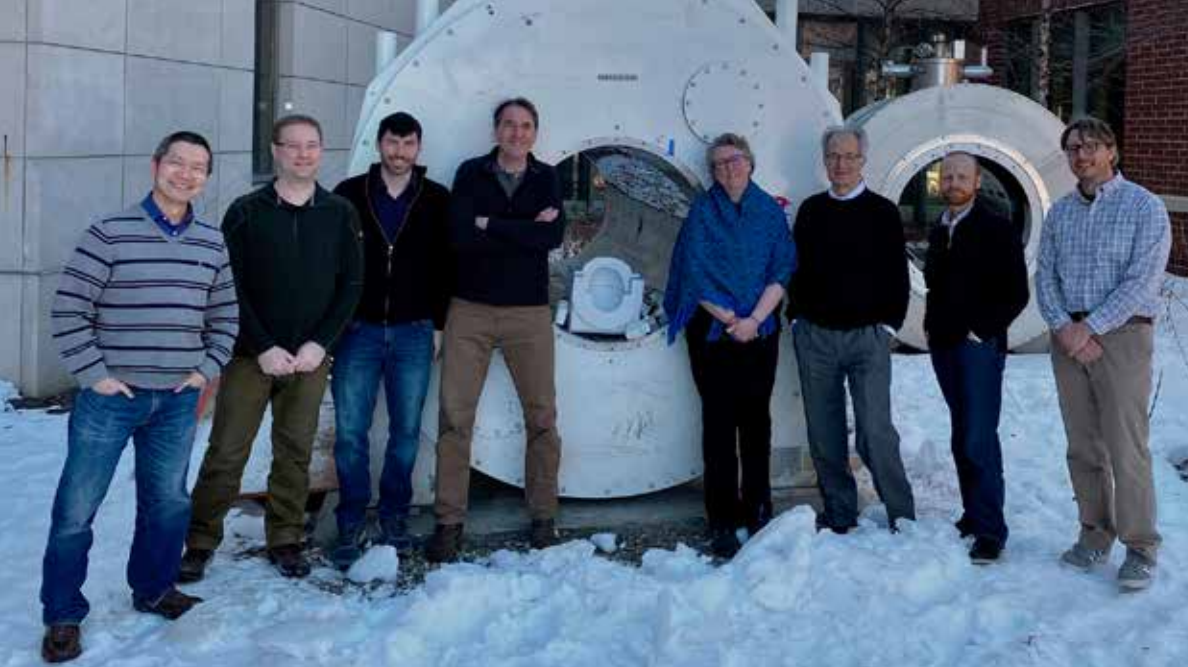
5. Uğurbil, K, Auerbach, E, Moeller, S, et al. Brain imaging with improved acceleration and SNR at 7 Tesla obtained with 64-channel receive array. *Magn Reson Med.* 2019; 82: 495– 509.

<https://doi.org/10.1002/mrm.27695>

<https://www.onlinelibrary.wiley.com/doi/10.1002/mrm.27695>

<https://blog.ismrm.org/2019/10/18/qa-with-russell-lagore-and-kamil-ugurbil/>





Pictured is the magnet with which the 64 channel data was obtained, and also happens to be the world's very first 7T magnet - pioneering the field of 7T research and its clinical applications. This magnet was decommissioned in December 2019. Pictured with the magnet from left to right: Xiaoping Wu, Edward Auerbach, Russell Lagore, Gregor Adriany, Andrea Grant, Kâmil Uğurbil, Matt Waks, Jerahmie Radder

channels. It is, in a sense, a marriage made in heaven. When you go to high field, you need a lot of coils to capture the SNR at the periphery. In the centre of the brain you capture the SNR with 32-channels at 7T and at 1.5T. At the periphery of the brain, which is a very important region, you need a lot of channels. Many channels may not work at lower fields. When you have small receiver loops, thermal noise becomes dominant, and you're not sample-noise dominated, which is ideal. But when you go to very high fields, you again become sample-noise dominated, so it works! The small coils work better at higher fields and I would not try a very large number of loops at 1.5T. It may not work very well.

**Russell:** You need to use sound engineering all the time when building arrays. We followed in the footsteps of other builders, and used low noise, low input-impedance pre-amplifiers. We were aligning them appropriately to optimise noise figure in magnetic fields to optimise SNR wherever possible.

**MRMH:** Your results show that your coil easily outperforms the Human Connectome Project's 32-channel coil. What is the biggest implication for functional and structural brain studies?

**Kâmil:** I think the implications are quite significant. In fact, the limitations that we ran into when developing the Human Connectome Project motivated us. We spent quite a bit of time on optimising Human Connectome data acquisition, and there was always a tension, a give-and-take, between spatial resolution and the rate at which you can collect data. For example, in functional resting state connectomics, some people were pushing for millimetre to submillimetre spatial resolution, to see different cortical layers connecting to different areas. But the Human Connectome Project was a whole-brain initiative, and whole-brain acquisitions got too long. You couldn't sample the oscillations in the brain fast enough, so the number of networks we could detect decreased. We made a compromise at the end, which did not necessarily please the very high-resolution de-

manding people like myself, to stay on approximately one second for whole brain acquisition. And now, with a coil like this, we would like to revisit this, and go to something like millimetre resolution and yet stay under a second in terms of whole brain imaging.

**MRMH:** In the paper you also say that 64 channels is only the beginning. Do you have any projections for the future? Are there any trade-offs, or bottlenecks to 256 channels?

**Russell:** Our current effort is in 10.5T. One of the first efforts was to build a 32-channel receive, and here we spent time carefully optimising cable paths and circuitry in order to reduce the interaction between the transmitter and receiver. We wanted good transmit efficiency, and we wanted to reliably say that the transmitter works in the same way with or without the receive array. Moving on from that, we're at the design step of doing a 64 or maybe 72-channel coil. We haven't quite finalized how many channels to put on it. Moving on from that, we're looking at how to miniaturise all of our RF-electronics. I have built several primate coils that are very high density. How small the feed circuitry and the components have to get, has shown me that it is feasible. This could be extended and use the miniaturised electronics at 10.5 T, to achieve up to 128 channels. Part of this push is to miniaturise the pre-amplifiers themselves. They are small, but the supporting electronics are quite large. By putting everything onto a single board that attaches straight to the coil and then goes straight out of the coil housing on a cable, I think we can achieve 128 channels. Beyond that, we might run into an issue of real estate as the circuitry ends up overwhelming the size of the loops to the point that mirror currents and scattering from the coaxial cables dominate.

**MRMH:** Thank you so much, it was a really insightful conversation.

**Kâmil:** We were happy to participate in this interview, and hopefully we will do another one when we build a 128-channel coil. ■

“By putting everything onto a single board that attaches straight to the coil and then goes straight out of the coil housing on a cable, I think we can achieve 128 channels”

—Russell Lagore



# Free-base porphyrins as CEST MRI contrast agents

INTERVIEW BY **MATHIEU BOUDREAU**, TRANSCRIPTION BY **PUNEET BAGGA**

## EDITOR'S PICK FOR AUGUST

In this Q&A, we discuss the latest paper by co-first author Xiaoxiao Zhang and last author Xin Zhou, from the Wuhan Institute of Physics and Mathematics in China. Their paper presents a newly discovered CEST contrast agent with a very high upfield shift, which may be applicable as a contrast agent for tumors.

**MRM Highlights:** To start of you can tell us a bit about yourselves and your background.

**Xiaoxiao Zhang:** I am Xiaoxiao, PhD student of Xin at the Wuhan Institute of Physics and Mathematics. This is my first time with research in CEST MRI. We carefully took a look at some of the CEST contrast agents and finally we found that Porphyrin is perfect for CEST imaging.

**Xin Zhou:** I got my PhD from same institute where I am a faculty now, Wuhan Institute of Physics and Mathematics, which is affiliated with Chinese Academy of Science. Then in 2004, after PhD, I went to Harvard Medical School and did my postdoc in Department of Radiology for three years. After that, I went to UC Berkeley to be a Research Fellow with Alex Pines from 2007-10. In 2010, I came back to China and built my own lab from scratch starting with only myself in the lab. After about 9 years, now we have about 50 people in my lab, which is huge. In my lab, we have three directions, 1) medical imaging, which is mostly focused on Hyperpolarized Xenon Imaging; 2) we develop contrast agents for Imaging; and 3) we do atomic magnetometer for low field for ultra-low field detection.

**MRMH:** Is there anything limiting the use of this technique for more widespread use for clinical applications?

**Xiaoxiao:** Because porphyrin is a classically used in photodynamic therapy, so we can modulate the average function of porphyrin to get MRI guided therapy. Maybe this is more important, and we hope to continue the work in mice and clinical work.

**Xin:** I think another challenge is, because right now when we do the in vivo experiments, we inject the contrast agent intratumorally not intravenously. Also, due to the lower sensitivity of the CEST method, we have to inject higher amounts of the contrast agent. We have



**Xin Zhou**

to find out a way to lower the dose for the human applications. That is what we are working on to find out if we can integrate this CEST agent with a hyperpolarised medium to enhance the sensitivity. So far, we can use Xenon to achieve about a 100 pM range detection in vivo, so in the next experiments, we want to combine hyperpolarization and CEST to lower the dose for human studies in the future.

**MRMH:** Is there anything else you would like to share with our viewers about this discovery?

**Xin:** This idea originally comes from a very tiny signal, so I want to share this with both students and faculty members. When you find a very tiny signal, you should think about it and compare to the existing results to find out a new application. I recall a story about Erwin Hahn, who is the inventor of the spin echo. When I was at Berkeley, I talked to Erwin Hahn, and he told me how he found out the spin echo by just using the 90 and an-

“In the next experiments, we want to combine hyperpolarization and CEST to lower the dose for human studies”

–Xin Zhou

Zhang, X, Yuan, Y, Li, S, et al. Free-base porphyrins as CEST MRI contrast agents with highly upfield shifted labile protons. *Magn Reson Med*. 2019; 82: 577– 585.

<https://doi.org/10.1002/mrm.27753>

<https://onlinelibrary.wiley.com/doi/10.1002/mrm.27753>

<https://blog.ismrm.org/2019/08/23/qa-with-xiaoxiao-zhang-and-xin-zhou/>



The Zhou group (2017)

other 180 pulse. So now it's not an FID it's an echo, and from the first two experiments he threw the printout of results from the spin echo experiments into the trash bin. After two days, he found out that the signal in the experiments means something useful. It can be used for enhancing the sensitivity to get better SNR. Similarly, I really appreciate the mentorship from Erwin Hahn and Alex Pines, they taught me how to do research. Even when you have very tiny signal, just like noise, instead of ignoring that, you should find out how to use it and to amplify it so that it can be useful to other fields.

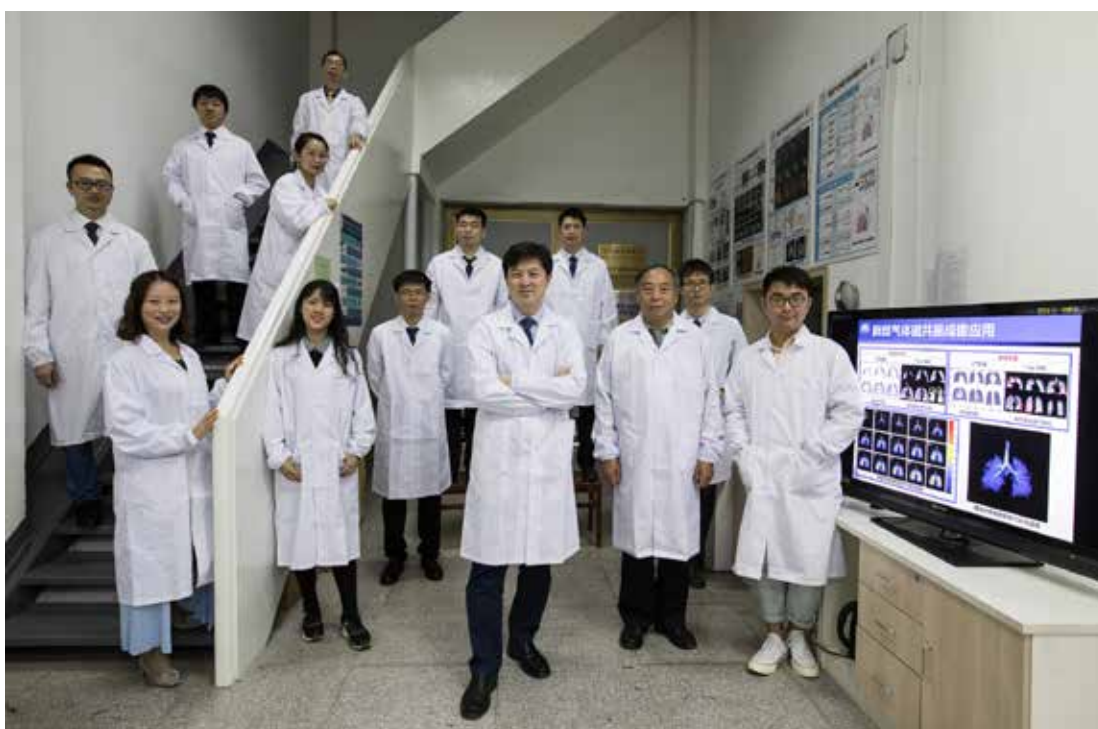
**Xiaoxiao:** When I do the CEST imaging, at first, I like to have a very simple MR microscopy. We can find some small thing described. This is very important to know about because it's very easy to get the MR spectroscopy and we can test on the high-throughput condition. The diaCEST effect is highly dependent on pH and anyone

who wants to try it, please check the concentration and average pH. This is very important. My suggestion is, try with another condition and think more about the structure.

**MRMH:** Maybe you have anything about your city Wuhan that you would like to share with the audience?

**Xin:** Oh yes! Wuhan is a very special city. Do you know which city has the highest population of graduate and undergraduate students in the world? The answer is Wuhan. The population of Wuhan city is about 10 million people, out of which 30% or 1.3 million are graduate and undergraduate students. Also, Wuhan in China is similar to Chicago in the USA. I will host a meeting for GMAT in 2021 and I would like to welcome everyone to visit us in Wuhan. Also, we have the National Center for Magnetic Resonance in China which is very important site for NMR advancement and development. ■

“The diaCEST effect is highly dependent on pH and anyone who wants to try it, please check the concentration and average pH”  
—Xiaoxiao Zhang



Members of the Zhou group in their lab in Wuhan



# Semi-Automated Analysis of 4D Flow MRI

INTERVIEW BY ATEF BADJI, TRANSCRIPTION BY JULIO GARCIA FLORES

## EDITOR'S PICK FOR AUGUST

In this Q&A, we discuss the latest paper by Alireza Vali and Susanne Schnell from the Department of Radiology at Northwestern University in Chicago. Their paper presents a semi-automated analysis pipeline of 4D flow MRI, which has been used to assess the hemodynamic impact of intracranial atherosclerotic disease.

“I think, in general when you use automated tools, I will always say you have to manually inspect the results”

–Susanne Schnell

**MRM Highlights:** Could you tell us a little bit about yourself and how did you begin involved in MRI?

**Alireza Vali:** I obtained my PhD in mechanical engineering with a focus in flow, computational modelling and flow measurements with different techniques, some of them optical techniques. In 2015, I started working in patient specific CFD modelling of blood flow to inform medical imaging. We used 4D flow MRI as a method to improve the accuracy our CFD simulations, and for validation of our results. Then, it was fascinating with this new technique based in MRI because my background was in particle image velocimetry, I knew how challenging it is to measure flow and this method was interesting because it can measure flow within the human body. It was interesting and intriguing for me. So, I decided to join the Department of Radiology at Northwestern University and work with the experts of medical imaging and flow imaging with MRI.

**Susanne Schnell:** I started working in MRI way back on 2003 the first time. I was writing on my Master's thesis in brain fMRI at University of Queensland in Brisbane. After that I moved away from MRI and start working in a proper job. But I always started how nice it was when I was working in MRI and I came back to do my PhD. It was 2006 when I started in Freiburg, Germany, in the lab of Jürgen Henning and ever since then I stayed in the field of MRI. I just changed a bit from DTI, and now to 4D flow MRI

**MRMH:** You develop a semi-automatic flow analysis pipeline that evaluates flow and velocity, and in the brain's entire vasculature. I was wondering if you were open science advocate and if you are considering



Alireza Vali

with Eric Schrauben in making your pipeline publicly available for other centres?

**Susanne:** We haven't talked about that with Eric, but we do completely agree that this is something we should actually do. I am currently the secretary of the Flow and Motion Study Group of the ISMRM. This is one of the topics we have in our list, that we create a shared platform, so that all the institutions will work in the same thing, share the tools and allows the exchange of pro-

Vali, A, Aristova, M, Vakil, P, et al. Semi-automated analysis of 4D flow MRI to assess the hemodynamic impact of intracranial atherosclerotic disease. *Magn Reson Med.* 2019; 82: 749–762.

<https://doi.org/10.1002/mrm.27747>

<https://onlinelibrary.wiley.com/doi/10.1002/mrm.27747>

<https://blog.ismrm.org/2019/09/13/qa-with-alireza-vali-and-susanne-schnell/>



grams and analysis tools. We will definitely approach Eric, suggest that our program had changed dramatically compared to what Eric had done before us. I think he will agree since he gave it to us, this is definitely something we will do and allow other researchers to use the same tools.

**MRMH: What you can say to other scientists wishing to use your pipeline. What should they be cautious about?**

**Alireza:** I will say like any other post-processing in medical imaging, the quality plays an important role, the quality of images in the accuracy of the analysis. If they have poor quality images to start with the analysis will not be good. Both the images techniques and the post-processing should go hand in hand. It should be



**Susanne Schnell**

high quality images to start upfront. One thing that was challenging in this workflow was the segmentation of vasculature which is very important and has a significant effect on the calculation of flow analysis. The multimodality approach combining time-of-flight MRA with 4D flow MRI can improve the segmentation. But you have to know that these images are acquired in different spatial resolutions and don't match exactly. I be-

lieve the segmentation is the area that can be improved using more advanced algorithms.

**Susanne:** I think our tools are as automated as possible, it is important that the researcher inspects the results. If data quality is not good you have to manually correct the results. I think, in general when you use automated tools, I will always say you have to manually inspect the results. The other important thing is that these tools are the second tool in the pipeline. 4D flow data always have to be first corrected for noise, eddy currents, and if necessary for aliasing. Then you can start using this semi-automated analysis tool.

**MRMH: You apply your analysis tool to characterize hemodynamic impact of intra-cranial atherosclerotic disease. Were you surprised by the pressure drop results between patients with severe and moderate stenosis?**

**Susanne:** I was surprised because the results were very distinct, and I did not expect that. Especially since we used Bernoulli which uses a lot of assumptions that we are actually not fulfilling. I was very surprised by how close the CFD simulations were with Bernoulli at the end. We were lucky to see that.

**Alireza:** I agree. Coming from the mechanical engineering background at the beginning I was not sure about this method because it is simple. It can be used for distinguishing patients with different level of disease. We decided to examine our method in flow phantoms against CFD, a more advanced technique for pressure drop calculation. I was surprised that this method was sensitive to different flow rates and degrees of stenosis, as we presented in the paper. Knowing this sensitivity, the simplicity of this method can be advantageous because in clinical applications we want the results quickly without the need for CFD which can take a long time.

**MRMH: What is the next step of this work now?**

**Alireza:** The analysis tool has been validated with experimental detail with flow phantoms and we compared it with commercial software tools that are more established. The results coming from this analysis tool are accurate and they can rely on that. They can use this analysis tool for applications in the aorta and the liver. We want to extend the capability of the program to make it more useful in other applications. We want to use it in clinical studies and investigate the links between the hemodynamics in the cardiovascular system and cerebrovascular disease.

**Susanne:** I think the main factor is to apply the same kind of approach in other areas in the body. The workflow is still pretty complicated in analyzing flow in the liver. Liver would be a nice field where we also would like to investigate disease. So far 4D flow has been applied mostly in the aorta and heart. This is, of course, something that we would like to do, the workflow there is a little bit easier than in the small vessel areas. ■

“The simplicity of this method can be advantageous because in clinical applications we want the results quickly without the need for CFD which can take a long time.”

–Alireza Vali

# Whole-brain B1-mapping using three-dimensional DREAM

INTERVIEW BY NIKOLA STIKOV, TRANSCRIPTION BY SOPHIE SCHAUMAN

## EDITOR'S PICK FOR SEPTEMBER

In this Q&A, we highlight the latest paper by first author Philipp Ehes and last author Tony Stöcker, from the German Center for Neurodegenerative Diseases in Bonn, Germany. The paper is entitled "Whole-brain B1-mapping using three-dimensional DREAM" (DREAM: Dual Refocusing Echo Acquisition Mode) and below are their thoughts on B1 mapping and the importance of transparency in research.

“We have quite a few studies that require B1 mapping. A quick 5-second scan on every study protocol is very helpful”  
–Philipp Ehes

**MRM Highlights:** Usually we start with some background questions, in particular how you got into MRI.

**Philipp Ehes:** I studied physics in Würzburg and there was a big MR group that I got sucked into. First of all, I started with NMR during my diploma thesis, and during my PhD I worked on relaxometry. After Würzburg, and a brief visit in Cleveland, I went to Tübingen, where balanced SSFP and functional imaging were my main topics.

**MRMH: And Tony, how about you?**

**Tony Stöcker:** I studied at the University of Bochum. I studied geophysics and did my PhD in seismic tomography. I entered the field of MRI afterwards, and started in functional imaging in the year 2000 at the clinics of

Dusseldorf. Afterwards I worked with Jon Shah at the Research Centre Jülich before I had the opportunity to have my own research group here, at DZNE Bonn.

**MRMH: How long have you been in Bonn, leading your group?**

**Tony:** The DZNE is a rather young institute. It opened in 2009, and I joined in 2012. We got the scanners in 2013.

**MRMH: This work is a follow up of the original DREAM sequence that came from Börner in 2012. You managed to make it 3D and you managed to make it fast. Philipp, can you tell us about the path from that 2012 paper to 3DREAM today?**

**Philipp:** In the beginning I wasn't even here, so the main idea is from our predecessor, Daniel Brenner, he started



Tony Stöcker



Philipp Ehes

Ehes, P, Brenner, D, Stirnberg, R, Pracht, ED, Stöcker, T. Whole-brain B1-mapping using three-dimensional DREAM. *Magn Reson Med*. 2019; 82: 924–934.

<https://doi.org/10.1002/mrm.27773>

<https://onlinelibrary.wiley.com/doi/10.1002/mrm.27773>

<https://blog.ismrm.org/2019/10/11/qa-with-philipp-ehses-and-tony-stocker/>

with the 3D sequence...

**MRMH: There was an abstract in Milan I believe?**

**Tony:** Yeah! Originally, we spent a lot of time on 3D readouts and especially on 2D phase encoding and centre out, all cartesian. Daniel Brenner was doing a lot of



Research group members, from left to right: Anke Rueling, Yiming Dong, Ed Pracht, Rüdiger Stirnberg, Yannik Voelzke, Jenny Schlee, Tony Stöcker, Suzan Akbey, Philipp Ehse, Difei Wang, Martin Schidlowski, Sascha Brunheim, & Marten Veldmann.

flip-angle imaging. Then the DREAM paper came out and we thought ‘wow!’ that’s really a cool technique. Because we were working on 3D readouts, we thought ‘let’s try to do that with DREAM’, and the result of that was our ISMRM abstract in Milan. From the first idea to a working technique was quite some way, and in that Philipp was very involved.

**MRMH:** So, Philipp, how long were you working on this? Was it since you came to Bonn?

**Philipp:** Basically yes. There were other projects as well, but this was my main scientific topic since I came here.

**MRMH:** It seems like the biggest challenge you are facing here is blurring. And trying to compensate for it required some additional blurring. Rather than trying to go for an average T1 value and estimate what the blur might be, what if you just tried to blur at the end. Do you think this might also work as a somewhat simpler approach?

**Philipp:** It may work, but in the end, the reason for the artifact is that the blurring is different in the two images. Depending on how much blurring you add, it may work, but I think it’s better to use the signal equation...

**MRMH:** Absolutely! Here, there is an actual physical reason for doing the blurring. Any thoughts on the choice of the blurring parameters?

**Philipp:** The blurring is determined by the flip angle, the TR, the T1, and the length of the echo train. The flip angle we get from the experiment itself, and iteratively improve. T1 we just have to guess. We don’t want to do time intensive T1-mapping, so the simplest way was to use an average T1. The difference from this average T1 is not big, except for CSF, so it’s the best estimate we can get quickly.

**Tony:** And even if the T1 estimate is not very accurate, the effect on the flip angle estimate is not very strong.

**MRMH:** You spent a lot of time on making the code available and have a Jupyter Notebook on GitLab. Where did the motivation for that come from, and what do you hope to achieve by it?

**Philipp:** I have always profited from others making code available, and I think it’s a good idea. Maybe it will help to generate interest for the technique, so there are benefits for both sides.

**MRMH:** Tony, is this the practice for your lab? Do you

**publish most of your code as Jupyter Notebooks?**

**Tony:** Yes, absolutely, Jupyter Notebooks, C++, whatever... we try to do that if possible. For example, with Siemens sequences, it’s not so easy. I think it’s a very important aspect to being able to reproduce research. Making the whole thing available makes everything easier and faster. That is what we would like to support.

**MRMH:** And what about the pulse sequence? How easy is it to implement, and how easy would it be to port to another site?

**Tony:** We can only speak for Siemens. Implementing it from scratch would be a lot of work. Sharing code is not that trivial, but we do share it via Siemens binaries, C2P.

**MRMH:** How many centres are running this sequence at the moment?

**Philipp:** We counted that recently, and it was 18, I think.

**MRMH:** That’s very impressive. Do you think it might become a stock sequence at some point?

**Philipp:** It’s still at the C2P state. Other than that, we don’t know yet.

**MRMH:** It’s really nice to see reproducible research promoted in Highlights, and we hope that people will consult your code and implement 3DREAM. Going forward, what would you like to do with 3DREAM?

**Philipp:** We now want to apply the technique. We have quite a few studies that require B1 mapping. A quick 5-second scan on every study protocol is very helpful. In addition, we want to go to parallel transmit and B1 shimming, and in this case it’s also very useful to have a quick way to run a B1 scan for all 8 channels.

**MRMH:** And Tony, what kind of applications are you considering? Is it basic T1 mapping or something a little more involved on the quantitative MRI side?

**Tony:** If we want to be quantitative, we need to know the flip angle, and in that sense it’s really a general tool. We also suggest that users, who want to set up new studies, use it even if they don’t know exactly why they would need the flip angle. It’s just a few seconds and it can help them later on in different approaches to quantitative MRI, multiparametric or T1 mapping. For design for parallel transmit it’s also required, but we are just starting to use it and get more knowledge about it.

**MRMH:** Wonderful, thank you. ■

“If we want to be quantitative, we need to know the flip angle, and in that sense it’s really a general tool”

–Tony Stöcker



# Mammographic density by single-sided portable NMR

INTERVIEW BY ATEF BADJI, TRANSCRIPTION BY JULIO GARCIA FLORES

## EDITOR'S PICK FOR SEPTEMBER

In today's interview, we discuss the latest paper by Tonima Ali and Konstantin Momot from Queensland University of Technology in Brisbane, Australia. Their paper presents a T2-based portable NMR analysis approach to quantify elevated mammographic density.

“I spent quite a few years doing imaging research and this portable NMR project is really a hybrid between spectroscopy and imaging”

—Konstantin Momot



Konstantin I. Momot

**MRM Highlights:** Could you tell us a little bit about yourself and how did you become involved in MRI?

**Tonima Ali:** For myself, I just finished my PhD. The paper we are talking today was the last publication out of my PhD work. I did my Masters where I developed software to look at MRI and during the PhD I started to explore MRI in more detail, so that's fun. I got in touch with Konstantin and learned a lot more.



Tonima S. Ali

**Konstantin Momot:** I came to MRI through NMR spectroscopy because I am physical chemist by training. I did my PhD in physical chemistry, I spent a few years after my PhD just doing spectroscopy work and then I gradually gravitated towards imaging. I spent quite a few years doing imaging research and this portable NMR project is really a hybrid between spectroscopy and imaging. In a way, this is coming back to spectroscopy but by imaging.

**MRMH:** Could you tell us how you became involved in this particular work?

**Tonima:** We were interested to look into breast density and given the situation in current clinical practice, it's usually done by x-ray mammogram. It's good but there are a lot of limitations that have been talked about in literature before because it's a 2D projection of a 3D

Ali, TS, Tourell, MC, Hugo, HJ, et al. Transverse relaxation-based assessment of mammographic density and breast tissue composition by single-sided portable NMR. *Magn Reson Med.* 2019; 82: 1199– 1213.

<https://doi.org/10.1002/mrm.27781>

<https://onlinelibrary.wiley.com/doi/10.1002/MRM.27781>

<https://blog.ismrm.org/2019/11/15/qa-with-tonima-s-ali-and-konstantin-i-momot/>



The research team, with Konstantin Momot 3rd from the left.

object. So there can be artifacts that can lead to misdiagnosis and also the ionizing radiation is there. Doing MRI we do know that it's safe but that cost is very high for MRI. We were looking for an alternative that could make a bridge between the two and animal models were an excellent option because it's a desktop system, it's portable, it's relatively cheap. We did some initial experiments which looked good and then we eventually went into the breast density to explore.

**MRMH:** Could you tell us a bit about the technical limitation in using an inverse Laplace transform approach to reconstruct the T2 distribution?

**Tonima:** That has been something we needed to look at in fair bit of detail. We explored different methodologies because the inverse Laplace transform, the basic algorithm is the same but the software or the particular script that's used has been developed in different labs in different ways. We chose the one that allows you to draw a curve that would plot the relative amplitude of the chi-square against the alpha. There were a lot of relaxation data points, so it's relatively easy to do the analysis. When we are trying to find the minimum error using the inverse Laplace transform there always comes the issue of over smoothing it or under smoothing it or getting the right fit. Initially, it was not very obvious which distribution we were going to get correct. Once we looked into more and more for the breast tissue that we were looking at there's a proportion of fibroglandular tissue and another proportion of fat. Sometimes when you would see one bigger distribution that would mean we are over smoothing it. The structure of it would tell us whether we are getting the distribution right or wrong.

**Konstantin:** As Tonima said the inverse Laplace transform is quite sensitive to the smoothing parameter regularization and your inverse Laplace spectra which two distributions still look quite different depending on what is the value of the regularization parameter. What

we actually realized is that when you just look at the relative areas of fat and water peaks they're actually fairly insensitive to the exact value of the regularization parameter. So even if you slightly over smooth or slightly under smooth the transforms, within a very wide range it doesn't really affect the percentages of fat and water that we extract. You have to massively under smooth for the answer to be wildly off. I think it is actually a very good technique to use. I think it is very robust for what we're trying to achieve with it. We are comfortable with quantifying the amount of fat and water using inverse Laplace transform.

**MRMH:** Were you surprised by the results?

**Tonima:** When I looked at it for the first time, just based on the prior study we did where we looked at the T1 of the same breast samples, for this one when I started using inverse Laplace transform I was not personally expecting such a big peak from the fat. Our goal was really to try to find the deficient effect on the value of T2, how it moves, but we didn't, we found the T2 was a much better marker. I did look to this result a good number of times using different alpha values and different distributions but it was really a very good technique. I approached Konstantin, you know, this is what I found what do you think and we just took it forward and I think Konstantin is doing more work on it now.

**Konstantin:** I guess the results were surprising initially because our initial mindset was that we were expecting to see the value of the T2 itself change with the relative value of fat and water but if you look at the final figure in the paper, we see that the value of the T2 of fat and the T2 of water is fairly insensitive to the relative amounts. What we see is the change in the relative area of the fat and water peak but not the position. Took us some time to change the mindset to go from expecting to see changes in the T2 to just analysing the changes in the area of fractions. That is what we used for the analysis of this paper. ■

“Doing MRI we do know that it's safe but that cost is very high for MRI”

–Tonima Ali

# Sub-millimeter T1 mapping of rapidly relaxing compartments

INTERVIEW BY MATHIEU BOUDREAU, TRANSCRIPTION BY JANA HUTTER

## EDITOR'S PICK FOR OCTOBER

In this Q&A, we discuss the latest paper by Robert Claeser, Markus Zimmermann, and N. Jon Shah from the Institute of Neuroscience and Medicine at the Jülich Research Centre in Germany. Their paper presents a gradient-delay corrected implementation of the spiral TAPIR (T1 mapping with partial inversion recovery) pulse sequence, which was used to acquire sub-millimeter T1 maps of rapidly relaxing compartments.

**MRM Highlights:** Maybe to start off you could tell us about a little bit about your background and how you got into this work?

**Robert Claeser:** I got into MRI imaging via digital imaging from Electrical Engineering. I got to medical imaging for my diploma thesis and when I had a look at these images I realized that compared to conventional imaging using cameras the image quality is quite poor and I wondered why that might be the case.

**Markus Zimmermann:** My background is also Electrical Engineering. I also went from digital image processing into medical imaging. What interested me most is the numerical optimization that we find in compressed sensing applications.

**Jon Shah:** My background is somewhat varied. I started with low temperature physics in NMR spectroscopy and then I moved over into MRI. I first worked at the University of Cambridge, the mantra was that NMR is a quantitative technique and MRI is not, so let's try to make MRI quantitative as well. The problem is simply that it takes a long time. We've been doing quantitative imaging for a long time here and one of the latest pieces of work is this spiral technique.

**MRMH:** Is there anything limiting the widespread use of this technique at the moment or do you think there's more work that needs to be done before it's more widely implemented?

**Robert:** For one, we should increase the acceleration factor, there's clearly enough room in the SNR to do that. We should also speed up the reconstruction process. The current implementation is in Python and can be

improved with multi-processing or a lower level computation language to help proliferation.

**MRMH:** Do you have any applications in mind to use this technique?

**Robert:** Dementia research is an interesting topic because you really need a big study group. Having an elegant scanning technique helps and if you are scanning people who already suffer from an illness you might as well just get the scanning time short.

**Jon:** So clearly we're trying to go off to the fast relaxing components and that implicates Myelin-water straight away. Once you are able to look at that effectively then a lot of neurological diseases come into play. We are planning a big study on MS patients.

**MRMH:** With submillimeter you can almost start looking at the gray matter - is that something you're looking into as well?

**Jon:** I think to begin with white matter - the low-hanging fruit - but especially the MS collaboration would be very interested in looking at gray matter.

**MRMH:** Do you have any advice for people that would like to implement this pulse sequence, are there challenges that you had to overcome?

**Robert:** The implementation depends very much on the scanner you are working with. It's not a standard sequence and you cannot use a lot of the standard tools that are available. So you have to come up with a lot of solutions in the source code and that's the biggest challenge in implementing.

**Markus:** It feels a bit like fighting the system when you want to try to implement these non-cartesian sequences. As a programmer you might know how you want to implement the sequence and then you have to not do it this way but use a different way that just works and that sometimes feels a bit exhausting.

**Jon:** So having gone from programming these scanners myself to now not programming them but watching what people do, I think what's very clear to me is in the old days the gradient delay correction was a parameter that you had good control over. In successive over suc-

“I have this mantra of submillimetre sub-1% accuracy”  
-N. Jon Shah

Claeser, R, Zimmermann, M, Shah, NJ. Sub-millimeter T1 mapping of rapidly relaxing compartments with gradient delay corrected spiral TAPIR and compressed sensing at 3T. *Magn Reson Med.* 2019; 82: 1288– 1300.

<https://doi.org/10.1002/mrm.27797>

<https://onlinelibrary.wiley.com/doi/10.1002/mrm.27797>

<https://blog.ismrm.org/2019/10/25/qa-with-robert-claeser-markus-zimmermann-and-n-jon-shah/>





Shah group photo, with Jon Shah 3rd from the right.

cessive generations of programming environments the manufacturers seem to have hidden these things away from not just a user but even the IDEA programmers. I think this method that these two guys came up with is something that's looking quite useful and could actually be applied widely in particular to non-Cartesian trajectories. With the Cartesian trajectories - this was the argument right at the start of their work - you have the same delay for every line and it's really easy to correct but not with Cartesian trajectories. So I think this helps a lot for many people who want to do not Cartesian imaging.

**MRMH:** Is there anything else you'd like to share with our viewers about this worker about your broader research interests?

**Jon:** So the first goals have been achieved. I have this mantra of submillimetre sub-1% accuracy. I think a lot of people in the field of quantitative imaging don't pay too much attention to accuracy and precision and I have the opinion that the whole of quantitative imaging lives and dies by accuracy and precision. We have been working around resolutions of a millimetre for a while but never really being able to get to that sub-1% accuracy and one of the thoughts that comes to mind of course is that maybe it's partial volume that is causing these broader distributions. By getting submillimeter resolution maybe we'll get over that. That's where we're trying to go with actually trying to combine a number of correction techniques. One is also correcting for motion. We're looking at navigators that can be built into these sequences to get rid of those line-by-line shifts - in this case truly

trajectory-by-trajectory shifts. I think once we get to something that really is submillimeter - so 1% - in a reasonable acquisition time which I used to define as under 10 minutes, I'm starting to think maybe under 5 minutes, I think we open up the field quite a bit for really careful analysis of neurological diseases and progression.

**Markus:** Another point would also be to take into account the not only are there partial volume effects but also a tissue microstructure which means at some point you can't go lower in resolution or it becomes more and more difficult. To resolve it temporarily and then have a look into the different compartments might be another step towards higher accuracy.

**MRMH:** We usually ask people to share with us what they enjoy doing when they're not in the lab or if there's anything about as you like that you like to share with the audience.

**Robert:** I try to do some karate, I've been on a pause for a while but I'm looking to get back into.

**Jon:** Running the lab is quite a demanding time demanding activity. I tend to travel quite a bit for holidays and that's normally to one place where we enjoy the beach and sunshine. Apart from that I spend my time house building which is an ongoing project. It started some time ago actually but I'm quite enjoying it, it's quite therapeutic building something with your hands rather than with brainpower.

**Markus:** I've played piano for like more than a decade now and really enjoy that. I'm living close to Juelich in Aachen and there are some very nice swimming pools and I like to go swimming in my free time. ■

6

*“As a programmer you might know how you want to implement the sequence and then you have to not do it this way but use a different way that just works and that sometimes feels a bit exhausting.”*

–Markus Zimmermann

9

# Design of gradient waveforms for tensor-valued diffusion encoding

INTERVIEW BY NIKOLA STIKOV, TRANSCRIPTION BY AMY HOWARD

## EDITOR'S PICK FOR OCTOBER

In this Q&A, we highlight the latest paper by first author Filip Szczepankiewicz, from Brigham and Women's Hospital in Boston, and last author Markus Nilsson, from Lund University in Sweden. Their paper is titled "Maxwell-compensated design of asymmetric gradient waveforms for tensor-valued diffusion encoding".

“To me they are the Baba Yaga of MRI”

–Filip Szczepankiewicz

### MRM Highlights: What brought you both to MRI?

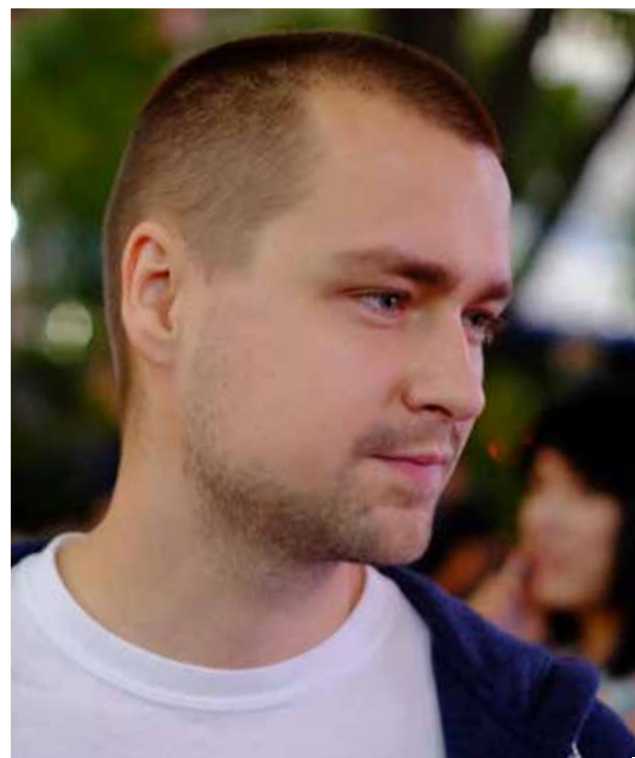
**Filip Szczepankiewicz:** I was studying to become a medical physicist doing when I first met Jimmy Lätt who later became my first supervisor. He showed us diffusion tractography, or something similar, and it blew my mind. I got to know Markus back then in 2012/13 and we've worked together ever since.

**Markus Nilsson:** I started in Lund back in 2006, with a master's thesis implementing a stimulated echo sequence for diffusion with variable diffusion times. I had a friend doing a master's thesis in our Professors group who said "look I have a friend who also likes MRI, can we bring him in as well?" They were quite reluctant to bring me in, but in the end they did. Then I did what I shouldn't do – I went against all the career advice you can get in academia of moving around - I stayed on and did my PhD, was a staff scientist and now I'm faculty.

### MRMH: Can you explain the concept of concomitant gradients. What are they? Why are they important, and why are they a problem?

**Filip:** To me they are the Baba Yaga of MRI. Sometimes you see something wrong and people pull eddy currents or concomitant fields out of the air as the placeholder for some explanation. In very simple terms, concomitant gradients are always there - as soon as you want a linear gradient. If you design things to be symmetric around the 180 pulse the effects due to the concomitant gradients tend to negate each other.

**Markus:** I have no clue exactly how to derive them but there are a few very nice old papers - one from Bernstein in 1997 that goes through in great detail. When we started this, there were some very complex look-



Filip Szczepankiewicz

ing equations and I thought that there must be a way to simplify these expressions – e.g. by using matrix multiplication or vectoral math. Then I read the paper and thought "oh, this is a bit more challenging than I thought".

### MRMH: How easy is it to implement this correction, both on the scanner and for other people to use it?

**Filip:** I don't think we should see this primarily as a correction - rather a technique to estimate the error and properly design the waveform so that it is not a problem. For this we've put up open-source code on GitHub where you can plug your experiment into the framework and see if it's going to be a problem. Or using the optimiser you can design a waveform where the con-

Szczepankiewicz, F, Westin, C-F, Nilsson, M. Maxwell-compensated design of asymmetric gradient waveforms for tensor-valued diffusion encoding. *Magn Reson Med.* 2019; 82: 1424– 1437. DOI: 10.1002/mrm.27828

<https://onlinelibrary.wiley.com/doi/10.1002/mrm.27828>

<https://blog.ismrm.org/2019/11/22/qa-with-filip-szczepankiewicz-and-markus-nilsson/>

comitant gradients will not be a problem. That's how we see the solution. It could be used to retrospectively correct the data - because you can just divide by the error factor - but the limitation is that you have to know your experiment extremely well.

**Markus:** You would also have to know  $T_2^*$ .

**Filip:** Yes, that's one of the primers - object independence - and that's difficult as well.

**Markus:** Notably, we didn't have to do anything with the pulse sequence. Once we had optimised the new waveforms, the problem was addressed. It's not to do with the acquisition but the preparation - how you design your experiment.

**MRMH:** You did this in a 3T with a 80mT/m gradient.



**Markus Nilsson**

**For higher gradients this is even more of a problem, so in a way you are really setting the stage for further applications of this technique to higher gradient scanners.**

**Filip:** We've implemented this on a connectome scanner where we've designed waveforms so that even 300mT/m gradients are not a problem. Additionally, if you use this M-nulling - you calculate the Maxwell index and then restrain it to a certain value - you can also be robust against gradient non-linearities in the system. The connectome has fairly large gradient non-linearities and we have shown that we can simultaneously address that problem.

**Markus:** In preclinical systems - where you are imaging

at a much higher resolution - the small voxel mitigates much of this effect. With 1000mT/m and the worst type of experiment that we saw in the paper, a double diffusion encoding type experiment, the errors tend to be negligible with 100-200 micron sized voxels.

**MRMH:** What about multiband?

**Filip:** So that's a neat place where this fits in - our technique is completely compatible with multislice. Without multislice there is, in principle, an online correction that shifts the isocentre to wherever you want in space. So, if you're collecting a slice somewhere away from the isocentre you can "subtract" the concomitant field away from your waveform. Inside the slice there will be one point that is error free and the error increases with distance from that point. However, this online correction doesn't work with multislice. Our technique is both compatible with multislice and solves this problem at the same time.

**Markus:** A related topic would be diffusion-weighted spectroscopy where you also have large voxels which makes the problem worse. For diffusion-weighted spectroscopy you need to control for those concomitant fields.

**Filip:** Also, if you use g-slider or something similar where you excite a thick slab, the phasing through the slab will also be massive, so that is another method where this has to be implemented.

**MRMH:** You've made a lot of this code available on GitHub and I'm very happy to see it out there. Have you had other people try to use it, or other groups try to implement it on their own sites?

**Filip:** Yes, though I am often involved. I've seen it be successfully used from beginning to end. One example where it has been used without my input is by Grant Yang and Jennifer McNab where they combined waveform optimisation code from our collaborator Jens Sjölund with Maxwell compensation code by that group.

**MRMH:** Markus, is this effort to make your work transparent part of a larger effort of the group to improve transparency and reproducibility in MRI?

**Markus:** Yes. A while ago when we also merged the code bases between our group and Daniel Topgaard's group in physical chemistry. We were often collaborating and analysing the same data but from different perspectives. So, we made quite a conscious effort to build a code base that we could use across different labs. For example, we decided to use SI units which simplified life quite a bit. We also decided to make it available. Now it seems the only reasonable way of doing it. When I review a paper and there is no code, I think "how could I ever relate to your statement and your claims here if I can't go in and check what you are doing?" I can't really see how science will be conducted in 5-10 years from now without open sharing of code and eventually data. ■

“We made quite a conscious effort to build a code base that we could use across different labs”

–Markus Nilsson



# T1 $\rho$ -based dynamic glucose-enhanced (DGE $\rho$ ) MRI

INTERVIEW BY FANG LIU, TRANSCRIPTION BY PUNEET BAGGA

## EDITOR'S PICK FOR NOVEMBER

6

*“In terms of optimizing, I think, most important was to maximize the CEST effect by choosing the right saturation patterns because it really determines the exchange from glucose to water”*

–Kai Herz

9

In this Q&A, we highlight the latest paper by first author Kai Herz and last author Moritz Zaiiss, from Magnetic Resonance Center at the Max Planck Institute for Biological Cybernetics in Germany. Their paper is titled “T1 $\rho$ -based dynamic glucose-enhanced (DGE $\rho$ ) MRI at 3 T: method development and early clinical experience in the human brain”.



Kai Herz

**MRM Highlights:** Could you please tell us a little bit about yourself, your background and about your overall research

**Kai Herz:** I am a medical student and I worked a lot on medical image processing especially segmentation and motion correction registration. During my master's thesis, I was working with some data from the 9.4 T scanner here at Tübingen and I got more interested in how sequences work, or the contrasts are generated and MR physics in general. And then I met Moritz here at the institute and the projects he offered were cool and he was cool as well, so I joined my PhD here. Now I am in my third year.

**Moritz Zaiiss:** I am a physicist by training and did a lot

of MR physics in Heidelberg at German Cancer Center. And for my second postdoc, I moved to Tübingen to Klaus Scheffler's group and they have nice 9.4 and 3T scanners there. I am mostly working on CEST imaging, that's what I did my PhD in. Mostly endogenous CEST, so, proteins, metabolites. Then the work started to go towards Glucose CEST, which is what this paper is about. I joined Tübingen not only for nice scanner, but because of European Horizon 2020 project called GLINT (Glucose CEST in Neoplastic Tumors). And the challenge was to bring the Glucose CEST that was already shown to work at ultra-high field and in animals, to bring it into clinical field strength. That's how I came to Tübingen and the Max Planck Institute and where Kai joined my team and where we created the article.

**MRMH:** Could you give a little bit introduction about what is T1 $\rho$ -based dynamic glucose enhanced imaging and how does this new technique compare with the more popular gadolinium-based perfusion imaging?

**Moritz:** First of all, I would say the biggest similarity is the idea or the protocol of injecting external contrast agent. For gadolinium, you take an image and then you inject gadolinium and take another image and you get a bright signal where gadolinium is. We use both the terms glucoseCEST and T1 $\rho$ -based glucose enhanced image synonymously because they are very related. The idea is still similar that we inject glucose and measure differences. However, first of all, the effect actually goes down when we have glucoseCEST. In glucoseCEST, due to the saturation transfer, the water signal goes down due to exchange between glucose and water. That means the water signal will be a little bit smaller where there is more glucose. At the same time, a huge difference, which we don't know yet is exactly what you asked, how does it compare to gadolinium. It seems that it's not just perfusion what we see in the DGE, dynamic glucose enhanced image does not match 100% with the gadolinium enhanced image. What we saw until now is if there is a BBB breakdown, then we also see some glucose uptake; however, the spatial correlation is was often different. Sometimes glucose

Herz, K, Lindig, T, Deshmane, A, et al. T1 $\rho$ -based dynamic glucose-enhanced (DGE $\rho$ ) MRI at 3 T: Method development and early clinical experience in the human brain. *Magn Reson Med*. 2019; 82: 1832–1847.

<https://doi.org/10.1002/mrm.27857>

<https://onlinelibrary.wiley.com/doi/10.1002/mrm.27857>

<https://blog.ismrm.org/2019/11/29/qa-with-kai-herz-and-moritz-zaiss/>



showed up more in the necrotic areas, and in some, in the gadolinium enhanced areas but in others, not. And to date, we do not know what is now more interesting in terms of activity of the tumour, for example. We know that there is some correlation between glucoseCEST and the pH, i.e., the glucoseCEST signal is higher when there is a lower pH. So, until now it is not clear how much of the total glucoseCEST effect is due to glucose concentration, perfusion, tissue or extracellular pH in this area. So, in a way, the original idea that we have used glucose as an alternative to gadolinium, is not the case yet, or it may never be, because it will be a different signal.

**MRMH: You have a background of image analysis, reconstruction and post-processing. What will be most challenging to bring a 7T technique into clinical MRI scanners?**

**Kai:** Most challenging are the things we cannot change, like the CEST effect is smaller and SNR is lower at lower field strengths. So, challenging part was to get a reliable signal despite all these lower effects. In terms of optimizing, I think, most important was to maximize the CEST effect by choosing the right saturation patterns because it really determines the exchange from glucose to water. And, the more effect you can create with the saturation pulses, the more CEST effect you can have irrespective of the scanner field strength. What was also very challenging is the motion correction. From previous work, we saw that even when there is a very small shift or volume mismatch, we can generate effects which are of the same size of expected DGEp of glucoseCEST signal. And, since we have a lower SNR, we also have larger voxels and partial volume effects. So, the most difficult and crucial part here was to perform motion correction.

**MRMH: I know you have been working on CEST for quite a long time. How does this work fit in your broad research pursuit, would you like to further develop this technique or apply this technique to clinical applications?**

**Moritz:** In a way, with CEST, we have opened the imaging world, especially at ultra-high field but also at 3T, to a metabolic contrast. What normally only have in spectroscopy, we now have as an imaging contrast. It's very challenging in CEST to really say, it is this specific molecule or this effect. But the larger goal is to have a metabolic MR which can help us to not only see the morphologic changes, we can also see perfusion changes like the tumour or disease has progressed a lot. What we want to see is very early, something is wrong with the metabolism, so maybe we should start a therapy right now or keep track of what is going on. I dream of 3D maps of not only morphology or structure, but of glucose levels, creatine levels, protein content, a 3D pH map to have a strong metabolic profile of the tissue which could then guide therapy response and early diagnosis. Just bring MR to a molecular MRI technique. I want to add, this is the goal, we are not there yet, we really tried our best to show that this method does not work, and we did not succeed, that is the message here. It is really a tiny effect and there are still a lot of problems with artefacts, so we have to be very careful. And this is all we can say that until now we could not disprove that it's possible. And of course, the larger goal is to make this technique very reliable. But I think to encourage the researchers, maybe they can follow us but there needs to be more work done in increasing CEST effect and have better SNR, higher resolution and make this really work at 3T. ■

**The CEST group from the Max Planck Institute for Biological Cybernetics in Tuebingen. From left to right: Kai Herz, Felix Glang, Sebastian Mueller, Anagha & Mark Deshmane and Moritz Zaiss.**

“We really tried our best to show that this method does not work, and we did not succeed”

–Moritz Zaiss

# Biophysically motivated estimation of $R2^*$

INTERVIEW BY EMILIE MCKINNON, TRANSCRIPTION BY AMY HOWARD

## EDITOR'S PICK FOR NOVEMBER

In this interview, we highlight the recent work by first author Sebastian Papazoglou and last author Siawoosh Mohammadi from University Medical Center Hamburg-Eppendorf. They propose a new biophysically motivated method for removing the orientation-dependent part of  $R2^*$  using a single GRE measurement. The authors show us some exciting results using 7T ex-vivo optic chiasm data and share their personal experiences about the project.

“Our inverse model is based on the hollow cylinder model, so it will of course depend on how well that model describes the physical reality.”

–Sebastian

**MRM Highlights:** To start, could you tell us a bit about your path into MRI?

**Sebastian Papazoglou:** Siawoosh and I wrote our masters theses on condensed matter theory in the same office in Hamburg. 15 years ago, I was offered a PhD position in Berlin, and the combination of MRI and Berlin convinced me.

**Siawoosh Mohammadi:** For me, I was finishing my master's degree in Germany at a time when you had to do either German military or civil service. My later PhD supervisor was offering a civil service position in diffusion tensor imaging - where the lab was building their own DTI fitting tools. It was cool because I was using the same kind of maths from condensed matter physics, but now applying it to biology.

**MRMH:** Some more specifics about the project. How did it get started?

**Sebastian:** It started in London with Nikolaus Weiskopf, since which many people have been involved in the project. I picked it up late 2017 or the beginning 2018 as a post doc project with Siawoosh.

**Siawoosh:** This work was inspired by the PNAS and Neuroimage papers by Wharton and Bowtell. The generative model really struck me: starting from the hollow cylinder model they could describe the signal. For me, what was missing was the inverse model to extract the biophysical model parameters. It was a very good starting point for the project.

**MRMH:** Can you tell me how dependent your results are on the accuracy of this hollow cylinder fibre model? Would things change if this was not an accurate



Siawoosh Mohammadi

approximation?

**Sebastian:** Our inverse model is based on the hollow cylinder model, so it will of course depend on how well that model describes the physical reality. If the model assumptions were violated, then the inverse model wouldn't work as well as it does in the publication.

**MRMH:** For example, would it matter if you had different  $T2^*$  relaxation properties in the different compartments?

**Sebastian:** In the hollow cylinder model, the signal is the sum of 3 exponential terms: the myelin, the axonal space and the extracellular space. In our model, we discard the myelin and assume that relaxation time for intra and extra-axonal compartments is the same. If you assume there is a difference between the two, you will likely have the difference of the two relaxation rates occurring somewhere in the Taylor expansion. I haven't done the calculations, so this is just intuition.

Papazoglou, S, Streubel, T, Ashtarayeh, M, et al. Biophysically motivated efficient estimation of the spatially isotropic  $R2^*$  component from a single gradient-recalled echo measurement. *Magn Reson Med*. 2019; 82: 1804– 1811. DOI: 10.1002/mrm.27863

<https://onlinelibrary.wiley.com/doi/10.1002/mrm.27863>

<https://blog.ismrm.org/2019/12/06/qa-with-sebastian-papazoglou-and-siawoosh-mohammadi/>



**Siawoosh:** It's an interesting question. Another question is, what happens if we are not working in the static dephasing regime, as we assume in the model. If this assumption is violated, we get a linear term in the solution which is orientation dependent and so cannot extract the isotropic part from the linear term and the anisotropic part from the higher order term. We are looking into this in more detail – can we determine the static dephasing regimes in different scenarios? Probably its different in vivo than ex vivo.

**MRMH:** Now you have these two metrics, one orientation dependent, the other orientation independent. The orientation independent parameter likely describes microstructure. Do you think there is interesting information in the orientationally dependent parameter?



**Sebastian Papazoglou**

**Sebastian:** Both parameters have complementary information. The second order term of the hollow cylinder fibre model holds lots of microscopic information - such as the fibre volume fraction, susceptibilities etc - and so likely holds quantitative importance. Also, a healthy myelin sheath has anisotropy, so it could also be a measure for the fibre integrity.

**Siawoosh:** The nice thing about the model is that, using a single contrast, we can disentangle these two parameters which probably come from different compartments. Our data hints that the parameters are sensitive to different microscopic features. We had two datasets that were differently fixed - one was PFA, the other 3% PFA and 1% formaldehyde. Interestingly, this changed the isotropic relaxation rate but not the anisotropic. But this was only one shot, and we only report one sample in the paper. These parameters are complementary

to the microstructural parameters from diffusion MRI – we also find one parameter which is orientationally dependent and associated with the fibre, and a second which is perhaps from the extracellular compartment.

**MRMH:** Have you tried it on a whole brain and do you see contrast in the white matter?

**Siawoosh:** This is really the crux of the model and what we are trying to understand – can we apply our model to an in vivo whole brain imaged at 3T. Here our TE is limited by physiology so that we cannot disentangle the two parameters. Furthermore, iron can have a second order decay term which will affect the model, and this will likely be very different ex vivo from in vivo. Will the model still be valid in vivo? So far, the data is just too noisy to answer this question. One thing we were looking at for the ISMRM was noise amplification. If you add another parameter into the model you can calculate the condition number of the matrix you have to invert in the linear model. The worse the condition number, the more sensitive the model is to noise. The condition number for the first order model, where one parameter is the offset and the second a linear decay, is of course much better than the second order model which has a third parameter with a  $TE^2$  dependence, because  $TE^2$  is not orthogonal to TE. So, the noise enhancement is 5x higher with the second order model rather than the first order model.

**MRMH:** Going back to the paper, Sebastian what was the biggest hurdle you had to overcome?

**Sebastian:** There was so much work to do with the code. For example, placing the region of interest to find reasonable locations. In the end, the model turned out to be really nice and straightforward and compact. But it was not easy work.

**MRMH:** Sebastian, what is the biggest take away from the paper and what does it bring to the community?

**Sebastian:** For the first time, we showed a way of separating these two terms – one isotropic and one anisotropic - from a single measurement. Of course, we have to see how it translates into in vivo, which is on-going work. I love the biophysical approach to modelling as it opens the window to measuring physical parameters.

**Siawoosh:** I think the holy grail is trying to unify the different contrast mechanisms within the biophysical modelling community. From the diffusion side, we can estimate the intra- and extra-axonal relaxation rates. From our relaxation side and are trying to separate the isotropic from the anisotropic part. Imagine you could find a way to fit gradient echo data and diffusion data simultaneously in a unified model. The anisotropic part can be estimated from diffusion data, whereas the other parameters, the microscopic features, can be estimated from their gradient echo data. If our model is correct, it could be a valuable contribution to community. The question now is whether it is still valid in vivo. ■

“I think the holy grail is trying to unify the different contrast mechanisms within the biophysical modelling community”

–Siawoosh Mohammadi

# Fast model-based T2 mapping using simultaneous multi-slice excitation

INTERVIEW BY PINAR ÖZBAY, TRANSCRIPTION BY JULIO GARCIA FLORES

## EDITOR'S PICK FOR DECEMBER

“One of the problems we wanted to solve here is also to get more accurate in terms of T2. It was the EPG simulation that gave for us the most accurate model.”

–Tom Hilbert

In today's interview, we highlight the recent work by first author Tom Hilbert, along with co-author David Norris and last author Tobias Kober from Siemens Healthcare in Lausanne Switzerland and the Donders Institute for Brain, Cognition, and Behavior at Radboud University Nijmegen in the Netherlands. Their paper is titled “Fast model-based T2 mapping using SAR-reduced simultaneous multi-slice excitation”.

**MRM Highlights:** Could you tell us a little bit about yourself, your background and how did you end up in MRI or maybe NMR?

**Tom Hilbert:** I studied computer science in my bachelor's in 2007. As part of my studies it was an internship which I did here in Lausanne where Tobias was my supervisor being a PhD student himself, almost exactly 10 years ago. I never left, he never got rid of me.

**Tobias Kober:** May I continue because you see, we are quite intertwined by our CVs. I did also my studies in Germany. I also did instrumentation as I studied something which is called computer engineering at the University of Heidelberg in Mannheim where I am from. Then here the slippery slope into MR began. There was a speciality which is called medical informatics and then I started to learn about MR and I found it super interesting and ever since I am stuck in MR. I did my Master's project on diffusion simulator with which I came here for my PhD.

**David Norris:** Well, I've been in MRI my whole professional life. I studied Physics and afterwards I did a Master of Science in medical physics in Aberdeen in Scotland. When I finished my masters I got kind of told if I wanted to do a PhD then this was my chance in this rather strange new thing called nuclear magnetic resonance imaging. That was back in the early 80s. I kind of realized again in recent years that I was very privileged because I did my PhD on the world's first full body MR scanner which was at 0.04 Tesla. I did a PhD in flow imaging and after that I went to Bremen in Germany. I stayed in Bremen for quite a few years, eight years, I think. After that I moved to Leipzig and that was in the



David Norris

period after the Berlin wall had come down, so I was kind of one of these pioneers foreigners and I worked at the Max Plank Society in Leipzig which was a very interesting and formative experience for me. I came to Nijmegen in 2001 and I've been working here happily ever after.

**MRMH:** Let's move to your exciting and interesting paper. Tom, would you like to tell us a bit more of this story?

**Tom:** At the beginning of my PhD, I was mostly working on accelerating T2 mapping. What we started off with was understanding which was the first obvious thing to do to make the sequence faster. We hit very quickly limits in terms of acceleration. We think, we managed an acceleration factor of 5, later a factor of 10, and at some point we didn't have enough samples. It couldn't

Hilbert, T, Schulz, J, Marques, JP, et al. Fast model-based T2 mapping using SAR-reduced simultaneous multislice excitation. *Magn Reson Med*. 2019; 82: 2090–2103.

<https://doi.org/10.1002/mrm.27890>

<https://onlinelibrary.wiley.com/doi/10.1002/mrm.27890>

<https://blog.ismrm.org/2019/12/20/qa-with-tom-hilbert-and-tobias-kober/>



Tobias Kober (left) and Tom Hilbert (right)

go faster. We were thinking, we would then understand the compatibility with simultaneous multi-slice. The problem was you have these four hundred eighty degree pulses that have so much power deposition. If you want to do a multiband pulse with them you exceed the SAR limit immediately. But there was this connection of the other Siemens guys said why don't use these PINS pulses that they developed. I think this is how it got initiated, in 2013-14. We got the pulses and we start working on it. The first simulations showed that the undersampling is compatible with doing simultaneous multi-slice. The heavy work was in implementing it.

**MRMH:** Maybe here, if you also describe what is special about the PINS pulses.

**Tom:** From my point of view, in a simple way is that in order to do simultaneous multi-slice, the easy thing you can do is multiplex, multiple pulses that have different frequencies. The problem is that multiplexing often results in peak amplitudes that might be clipped by the scanner or even hitting the SAR limits. With PINS pulses you are actually able to avoid this by undersampling and the aliasing of your pulse results in common slices that get excited instead of just a few slices.

**David:** It is a very good explanation. You have a peak voltage which you can try to get around that problem by changing the phases as the pulses you are adding in together but you cannot get around the fact that the power in the normal multiplexing procedure is proportional to the number of slices that you are trying to excite. If you think in a turbo spin echo sequence it runs in a way very, very fast in terms of power deposition which is the advantage essentially. You can look at it in different ways, but the way Tom explained is basically the Fourier property of multiplying by a comb function in the time domain will give you a convolution in the frequency domain allowing you essentially to excite an infinite number of slices for the same power as a for a single slice.

**Tobias:** It is using the power of an artefact. One special little trick, I remember long time ago - in the initial pa-

per there is only sagittal acquisition because you have an infinite comb of slices excited then you don't want all that signal, so in your transversal, you don't want the body signal. One thing you can do in every acquisition which is very practical, in the excitation pulse you do a classical multiband pulse heavy on SAR and then we have 16 refocusing pulses. They are these low SAR PINS pulses which are infinite, in a way, you know since you're only excited transversally the slices you want.

**MRMH:** The second powerful part of the project is the signal modelling, would you like to tell us about the modelling part of the project?

**Tom:** When I started working on this, we would typically use the exponential decay, removing the first echo due to stimulated echo effects, but in reality you still have an overestimation. One of the problems we wanted to solve here is also to get more accurate in terms of T2. It was the EPG simulation that gave for us the most accurate model. EPG stands for Extended Phase Graph simulation. With that simulation, we got very nice results that seems to fit the data well. It was a huge workaround basically to get a numerical model into an iterative reconstruction and this is what we call the soft reconstruction. It is a split algorithm for phase T2 mapping where we basically separate the reconstruction into a data consistency, trying to enforce similarity into the raw data, and a model consistency term when you try to enforce your reconstructed image to be similar to your simulated signals basically.

**MRMH:** Do you have anything to add David?

**David:** No, I mean, I really enjoyed the collaboration. I thought the paper was fantastic, you know to get to these acceleration factors is a tour-the-force. It looks excellent! I hope in long term some kind of implementation, at least on the Siemens systems with the move to more quantitative MRI. I think this sort of thing can be very important to really bring something for the patients. I mean, a normal T2 measurement was completely out of reach in past. ■

“

*“Multiplying by a comb function in the time domain will give you a convolution in the frequency domain allowing you essentially to excite an infinite number of slices for the same power as a for a single slice”*

–David Norris

”



# Automated free running 5D whole-heart MRI

INTERVIEW BY JESSICA MCKAY, TRANSCRIPTION BY MARK CHIEW

## EDITOR'S PICK FOR DECEMBER

In this Q&A, we meet Lorenzo Di Sopra, Matthias Stuber, and Jérôme Yerly, whose latest MRM paper introduces a user-friendly cardiac protocol that acquires 5D whole-heart images with just the push of a button.

“I don't think there is any MRI sequence in the world that collects more data per unit time of the heart than the sequence we are discussing here right now.”

—Matthias Stuber



Lorenzo Di Sopra



Matthias Stuber



Jerome Yerly

**MRM Highlights:** Can you guys start with a little bit of background about yourselves?

**Lorenzo Di Sopra:** Well, I started my PhD more or less three and a half years ago here at the university hospital of Lausanne with Matthias and Jerome. I've been working mainly on projects related to cardiac imaging, with a focus on the extraction of physiological information through different techniques.

**Matthias Stuber:** I did my PhD so long ago, I don't even remember. I think it was 1996, in guess what - cardiac imaging at the ETH in Zürich. I moved to Boston, did cardiovascular MRI, and then I became faculty at Johns Hopkins and guess what - cardiovascular MRI. Then 10 years ago, I moved to Lausanne and the rest is history. I was also the president of the

SCMR, the largest international society that caters to imaging of the heart.

**Jerome Yerly:** I finished my PhD in 2013 in Calgary with Richard Frayne. I was mainly working on neuroimaging, and then I moved to Switzerland in July 2013 and I started working with Matthias and I started doing cardiac imaging, and focus mainly on image reconstruction.

**MRMH: What drew you cardiac imaging?**

**Matthias:** I'm an electrical engineer by training, so I was always attracted to challenging technical problems. And at the time it seemed to me, the additional motion is a problem for MRI. I felt very fortunate to be able to be included in that research team at the time in Zürich and to work on that particular topic, and it has never left me. I still feel very passionate about how to solve these motion problems. That's why the research focus of my team is still there.

**Jerome:** I'm an engineer by training as well, and I was doing neuroimaging during my PhD, but every time I used to go conferences, I saw all those cardiac presentations my engineer side was always very interested in motion. When I met Matthias and his group back in 2012, I think at the SMRA in Utrecht, I got very interested with the project, and when he offered me a posi-

Di Sopra, L, Piccini, D, Coppo, S, Stuber, M, Yerly, J. An automated approach to fully self-gated free-running cardiac and respiratory motion-resolved 5D whole-heart MRI. *Magn Reson Med*. 2019; 82: 2118–2132.

<https://doi.org/10.1002/mrm.27898>

<https://onlinelibrary.wiley.com/doi/10.1002/mrm.27898>

<https://blog.ismrm.org/2020/01/10/qa-with-lorenzo-di-sopra-matthias-stuber-and-jerome-yerly/>



The group, from right to left: Jerome Yerly, Lorenzo Di Sopra and Matthias Stuber, “free-running” down the hallway.

tion in Switzerland I could only say yes.

**MRMH:** Maybe a silly question, but what does “free running” mean?

**Lorenzo:** When we talk about the free running framework, it’s a different approach to cardiac imaging that we have introduced. The idea behind the phrase free running is that instead of looking for specific windows of acquisition, for example during the cardiac cycle or during respiratory motion in which we hope to have a static condition of the heart so that we can acquire an image that is not blurred, the free running approach aims to acquire continuously, making the acquisition much easier. We deal with the motion in a retrospective way, after the acquisition, which increases the time efficiency of our acquisition and including much more information in our images.

**Matthias:** I might add, for people who are imaging the brain, it’s a no-brainer so to speak, that pulses are played out continuously without interruption. For cardiac guys like myself, this is unheard of, because you trigger the acquisition to the rhythm of the heart. Being able to continuously acquire data was not conceivable at the time, but now with modern tools this all of a sudden became possible. If you think about it, I don’t think there is any MRI sequence in the world that collects more data per unit time of the heart than the sequence we are discussing here right now.

**MRMH:** What exactly do the bins refer to?

**Lorenzo:** With what we call the 5-dimensional images, we have three spatial dimensions and respiratory and cardiac dimensions. That means that each single image reconstructed will be in a specific time-point along the cardiac cycle and in a specific position along the respiratory cycle. So each bin is one of those motion-resolved positions.

**MRMH:** Can you describe your triggers?

**Lorenzo:** Yes, so along the cardiac dimension, we use cardiac triggers to define a specific temporal position within each cardiac cycle. Obviously we have a long acquisition, and we need to align each single the cardiac cycle in a

consistent way so that we can take the information from all cardiac cycles of say, the systolic phase, and put all of this information that are consistent together. To do that, we first extract the self-gating signal, which is a signal with a certain temporal evolution, which will tell us the time point of the start of a new cardiac cycle, so we can align them. In the paper, we compare it to the ECG, which is our reference. This is a different approach from what is done along the respiratory dimension, because there we have a signal that we considered not in terms of temporal distance from a trigger, but rather the amplitude evolution of the signal. So we match one extreme with end expiration and the other with end inspiration, and we divide according to the amplitude of the signal.

**Matthias:** What I found fascinating when he was doing that research was that the mainstay of cardiac synchronization of the MRI experiment, the EKG, actually proved to be quite unreliable in that we discovered a lot of missed triggers. And we aren’t even talking about high magnetic field strengths where the so-called magnetohydrodynamic effect kicks in much more and makes it more difficult. So it was super interested to see that an EKG, that we depend on so much these days is not that reliable and we have to develop better tools to address the periodicity of cardiac motion.

**MRMH:** How long is the reconstruction time?

**Jerome:** We have a dedicated computer with a lot of RAM that is able to reconstruct the 5D dataset in about 5 hours. But again, we are interested in research, so we didn’t put any effort into optimizing the reconstruction - it’s trying to prove that the concept works. I’m sure that if industry is interested in getting that to customers, they will be able to reduce that reconstruction time by a factor of at least 10.

**Lorenzo:** It depends a lot on which dimensions and which resolution you are aiming for, so there really is a lot of flexibility in how you use the data that you acquired, and how you use them to reconstruct.

**MRMH:** Thank you so much for doing this. ■

6

*“The idea behind the phrase free running is that instead of looking for specific windows of acquisition, for example during the cardiac cycle or during respiratory motion in which we hope to have a static condition of the heart so that we can acquire an image that is not blurred, the free running approach aims to acquire continuously, making the acquisition much easier”*

–Lorenzo Di Sopra

9

## CONTRIBUTORS

### Mark Chiew

*Magnetic Resonance in Medicine Highlights Magazine Editor*

Mark is a University Research Lecturer at the University of Oxford. His



research interests

include the development of acquisition and reconstruction techniques for highly accelerated and robust neuroimaging. As for things that don't involve large and expensive magnets, Mark also enjoys eating noodles, wearing sandals, and spending time with his family.

### Mathieu Boudreau

*Magnetic Resonance in Medicine Deputy Editor for Science Outreach & Highlights Digital Content Editor*

Mathieu is a research fellow at the Montreal

Heart Institute, after having completing his PhD at McGill University. His current research interests are in developing open-source software for quantitative MRI techniques and other related image processing tools. In his free time, Mathieu enjoys cooking, hiking, and making grad students feel anxious about not having a proper backup of their computers.



### Atef Badji

*Magnetic Resonance in Medicine Highlights Q&A Editor*

Atef is an MD, currently working toward her PhD in Neuroscience at the University of Montréal.

Her research focus is on the quantitative evaluation of pathological states of the brain using MRI. Among her specific goals are the understanding of the white matter changes in the elderly, as well as the understanding of the natural course of multiple sclerosis. In her free time, Atef enjoys writing, eating chocolate, and watching Big Bang Theory with her husband.



### Puneet Bagga

Puneet is a Research Associate in the Department of Radiology at the University of Pennsylvania. He obtained his Ph.D. in Neurochemistry before joining Penn to pursue postdoctoral research in chemical exchange saturation transfer (CEST) MRI and MR spectroscopy at Penn. Puneet's current research focuses on developing new molecular imaging and spectroscopic techniques at ultra-high field MRI scanners. He is associated with ISMRM since 2011, he has received multiple summa/magna cum laude awards in addition to the Junior Fellow award in 2016. In his free time, Puneet enjoys playing guitar, photography, and traveling.



### Maria Eugenia Caligiuri

Maria Eugenia is a Post-Doc at the Neuroscience Research Center of Magna Graecia University in Catanzaro, Italy. She completed her PhD and part of her post-doctoral experience working at the Institute of Molecular Bioimaging and Physiology of the National Research Council. Her work focuses on advanced methods for multimodal MRI fusion and on their application in the field of neurological disorders and healthy brain aging. Maria Eugenia is the proud mom of Federico (a tiny human) and Pulce (a not-so-tiny cat), and in her free time enjoys listening to music, binge-watching TV series with her husband, and being a crazy-cat-lady.



### Julio Garcia Flores

Assistant professor at University of Calgary and researcher at the Stephenson Cardiac Imaging Centre where he leads the 4D flow MRI program. He is Fellow of National Researcher's System (SNI-I, CONACyT, Mexico) and Junior Fellow of the International Society for Magnetic Resonance in Medicine. He likes spending time with his family, good coffee and random music.



### Amy Howard

Amy is a final year PhD student at the FMRIB Centre, University of Oxford (UK). Her research looks at novel ways to combine complementary information from MRI and highly detailed microscopy data to both validate and drive biophysical modelling of the white matter. Outside of research, Amy is engaged in equality, diversity and inclusion initiatives, for example supporting and encouraging women in science through peer-support networks and public engagement activities.



### Jana Hutter

Jana obtained her PhD from the University of Erlangen-Nuernberg (Germany) in 2014, with a thesis on Compressed Sensing reconstructions for angiography. She moved to London to join King's College and the developing Human Connectome Project. Since being awarded a Sir Henry Wellcome Fellowship in 2016 she since focuses on fetal and placental quantitative MRI techniques.





## Agâh Karakuzu

Agâh is a PhD student in Biomedical Engineering with NeuroPoly Lab at Polytechnique Montréal. His research is centered on developing a reproducible quantitative MRI platform, with a particular focus on neurocardiology. He is an open science enthusiast and plays an active role as a science communication contributor for several platforms including MR Pulse and OHBM blog. He enjoys graphic designing, skiing and exploring specialty coffee.



## Fang Liu

Fang is an Assistant Professor at Harvard University and Massachusetts General Hospital. His research has focused on developing novel methods in image reconstruction, quantitative imaging, and image analysis using machine learning and artificial intelligence. In 2015, Fang received his Ph.D. from Medical Physics, University of Wisconsin-Madison, where Fang's research focused on designing new MR pulse sequences and developing MRI biomarkers for assessing and understanding musculoskeletal and neural diseases. Fang is a Junior Fellow of ISMRM and a passionate participant for scientific journal reviewing and editing. Fang also enjoys reading, hiking, and teaching.



## Jessica McKay

Jessica is a PhD student in the Biomedical Engineering Department at the University of Minnesota. She works at the Center for Magnetic Resonance Research where she is developing techniques for high resolution breast diffusion weighted imaging (DWI). She also enjoys downhill and water skiing.



## Emilie McKinnon

Emilie is an MD-PhD Candidate at the Medical University of South Carolina. She is currently finishing her PhD which focused on the application and development of diffusion MRI techniques at high b-values. In her free time, Emilie plays competitive roller derby for the Lowcountry Highrollers and for the South Carolina state team. In these circles she is better known as Waffle, named after the delicious treat from her home country Belgium.



## Krishna Nayak

Krishna is a Professor of Electrical and Computer Engineering (and by courtesy Biomedical Engineering and Radiology) at the University of Southern California. Krishna's current research includes 1) high performance low-field imaging, 2) real-time imaging of speech production, 3) cardiac perfusion imaging using arterial-spin labeling, and 4) sparse methods for quantitative dynamic contrast enhanced imaging. Krishna is a member of the ISMRM board of trustees, AMPC, and EDI task force. Outside of work, Krishna enjoys ultimate frisbee, basketball, music and dance, hiking, and family time.



## Pinar Özbay

Pinar joined Advanced MRI group at the National Institutes of Health in 2017, right after obtaining her PhD at ETH Zurich. During her PhD, she worked on novel contrast mechanisms for brain imaging, particularly quantitative susceptibility mapping at high field MR systems. At the NIH, she has been widening her interests towards fMRI, i.e. investigating fMRI signal characteristics during wake and sleep, together with physiological and EEG signals. She enjoys painting, stone carving and pilates, and is still discovering new coffee spots in DC.



## Sophie Schauman

Sophie is a final year doctoral student at the University of Oxford. The focus of Sophie's research is advanced image reconstruction methods, in particular methods applied to arterial spin labeling angiography. In addition to her research, Sophie is involved in many public engagement activities both in Oxford and at the ISMRM Magnetic Moments Competition. Sophie enjoys spending time outdoors, and is an enthusiastic member of her college rowing team.



## Noam Shemesh

Noam is an Associate Principal Investigator and Director of the Champalimaud preclinical MRI Centre at the Champalimaud Centre for the Unknown in Lisbon, Portugal. Before moving to Lisbon, he completed his PhD in Tel Aviv University and his post-doctoral studies in Weizmann Institute of Science. Noam's Lab investigates basic mechanisms underlying microstructural and functional modulations in health and disease via novel pulse sequences, advanced ultrahigh field MRI and MRS, cryogenic coils and other "toys". Noam especially takes pleasure in bringing the machines to the edge of their performance (amplifier meltdowns notwithstanding); outside the Lab, he loves watching sunsets with his wife and two daughters, playing guitar, and reading.



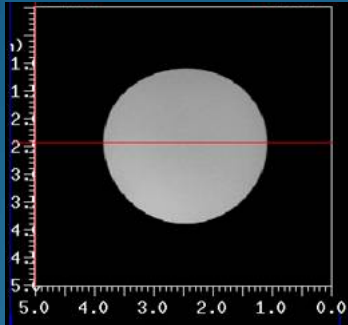
## Nikola Stikov

Prior to joining the faculty of École Polytechnique (University of Montréal), Nikola completed his post-doctoral training at the Montréal Neurological Institute, and his BS, MS, and PhD degrees at Stanford University. A son of a sports journalist, Nikola has made journalism his hobby by periodically contributing pieces on science and film to newspapers and blogs in his home country, Macedonia. His career and his hobby are finally united in Magnetic Resonance in Medicine Highlights.

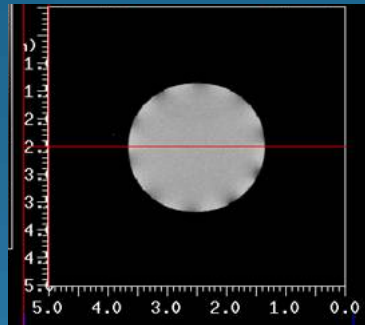


# Millipede Coils – Hundred-Element Birdcage Coils

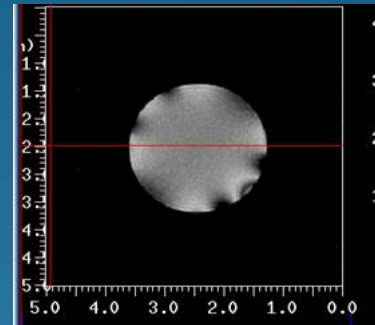
Extraordinary uniform RF profile for all imaging applications



Millipede coil



Birdcage coil



Saddle coil

- High RF homogeneity
- Quadrature drive – *high SNR, low SAR*
- Better filling factor – *better SNR*
- Range of IDs 5 mm – 40 mm and higher
- Wide range of frequencies 3 T – 16.4 T

