Four-dimensional Flow MRI: Principles and Cardiovascular Applications
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Jeffrey S. Klein, MD Hi. This is Jeff Klein, Editor of RadioGraphics and today I am pleased to have with us Dr. Arshid Azarine from the Department of Radiology at the Hospital Paris Saint-Joseph in Paris, France, who is the first author of one of our featured papers in the current May 2019 issue of RadioGraphics. His article is entitled 4D Flow Magnetic Resonance Imaging: Principals and Cardiovascular Applications. Dr. Azarine, welcome to our podcast.

Arshid Azarine, MD, MSc Hello and thank you Dr. Klein. It’s a pleasure for me to discuss with you today about our paper concerning 4D flow MRI imaging.

JSK Well we’re thrilled to have you. So let’s go ahead and begin. Now obviously there are some significant technical considerations regarding the performance of 4D flow MRI acquisition which your paper nicely summarizes in Table 1 of the paper. Let’s put this table up for our viewers and perhaps you can discuss some of the issues as they relate to optimizing spatial and temporal resolution on these acquisitions.

AA The purpose of the 4D flow MR imaging is to have access to velocity encoding data in any point within a 3D volume and this over time. So to say over a cardiac cycle. So in that temporal resolution is a big issue and as always in MR we have to do compromises with temporal and spatial resolution and also the signal. So as we are speaking about flow temporal resolution is really important. Most of the time we try to have less than 40 milliseconds of temporal resolution, but it’s not always possible because the sequence last longer. So we at least try to be that optimal for research at least. But most of the papers consider that the minimal that we can do is less than 60 milliseconds and we have to avoid temporal resolution more than 60 milliseconds. Now-a-days we speak more about cardiac frames than temporal resolution and we use about 20-50 cardiac frames. I usually, for current examinations, I use 30 cardiac frames which is a good temporal resolution about 45 milliseconds or something like that.

JSK Terrific. Now obviously in looking through your paper there’s considerable pre and post-processing of the data sets that are necessary to properly display the data for visual and quantitative flow analysis. Let’s take a look at Figure 1 as you explain how this all works from data acquisition to the final display and analysis of the data.

AA As you can see in this figure, we will have four volumes. One volume which is anatomic. This is the magnitude volume and we have three different phase difference volumes. In the three directions of the space, the right to left, superior-inferior, and anterior-posterior. And all these three volumes are phase encoded. That enables us to have isotropic volume with velocity encoding all the directions of the space. Once we acquired that data, we have four different volumes which consist of one magnitude or anatomic 3D volume and three phase contrast volumes which are encoded in the three directions of the space. So we have four volumes which are a big amount of data, about two gigs or three gigs. We push them into a computer, a very powerful computer, or sometimes on the workstation of the contractor and for some preprocessing for phase-offset or background corrections. Some part of this can be done by softwares locally, but you can also push all this data on cloud based software so you can be helped by the power of cloud processing and for that you need actually protective health information system to protect all the health information of the patient. But once you have pushed everything on the cloud, things go very faster and you can have AI based and deep learning based corrections of all these Maxwell terms and eddy currents and background corrections which allows you to access faster to the analysis part. Then you have the post-processing. The post-processing at first you have visual flow analysis. You see the flows, you see the velocity vectors, you see the streamlines which are incredibly actually nice. Also to see you it’s really comprehensive and you kind of understand again all the physiology of the flows. And then you can go at any point of your volume. You can do a quantitative flow analysis and you can measure current trends like forward flow, reverse flow, regurgitation, fraction, peak velocity; and you can push it even farther and use some advanced tools which are more dedicated to research now, like wall shear stress or kinetic energy loss.

JSK Terrific. So now let’s move on to some clinical applications of the 4D flow cardiovascular MRI. Beginning with the evaluation of congenital heart disease, the paper discusses the use of 4D flow in the evaluation of left to right intra and extra cardiac shunts in single ventricle patients who are post-Fontan operations for patients with repaired tetralogy of Fallot and in transposition patients after atrial switch procedures. Can you share with us how this technique has been used at your institution in this population of congenital heart disease patients? And then let’s look at movie three that I think nicely demonstrates the post-op cable pulmonary connections in a patient who is status-post Fontan surgery.
Yes. My institution which is more adult hospital. We have very few pediatric cases actually, but we have teenagers and a lot of congenital diseases have been discovered incidentally actually with young footballers who had dilation of the right ventricle and nothing was demonstrated by cardiography and we found very difficult sinus venosus of pulmonary vein abnormal returns and of course you have the tools to demonstrate it, but as they had MR to rule out ARVD for instance, we used 4D flow to also demonstrate and find this congenital incidental findings. But concerning grownup adults who have been operated for Fontan operations of people with transposition of red vessels and we have a big number of adults now with congenital heart disease which has been operated and we follow them with MR and the 4D flow it’s an amazing tool for that because most of the time we don’t even know what they exactly have. And with the 4D flow we can exactly see all the anatomy and go and measure the flows where we didn’t even suppose that point would have been interested to do 2D phase contrast sequence there. So it’s very interesting for this point of view. This retrospective analysis when suddenly you have an idea you can go at any time from any computer or laptop and you go to your volume and you can measure again something that you just thought about. And when considering the Fontan operation, you have tons of papers coming out because it is very interesting, the 4D flow shows where the blood from the superior vena cavaicles to the pulmonary arteries and the distribution and can see if there is harmonious or not harmonious distribution of the blood flow coming from the hepatic veins which has very important consequences for these patients.

Now addressing patients with cardiac valvular disease, you detail the use of this technique in patients with valvular regurgitation for example, and in assessing patients who have undergone transcatheter aortic valve replacement or valve replacement surgery. Clearly echocardiography remains the primary imaging modality in in the assessment of these patients but perhaps you can elucidate on what 4D-flow might offer for the assessment of these patients. As you do this we’ll display Movie 7 in the article that demonstrates tricuspid regurgitation on 4D flow cardiac MRI after bioprosthesis valve repair.

Of course, echocardiography is the first step but we know that there are some limits. And prosthetic valves can be a limit because they have a lot of artifacts at echocardiography. The other limits is everything happening in the right side, in the right ventricle. The trick is with valvular prosthesis is even more difficult and the pulmonary valves, also prosthetic valves, are and the prosthesis are also very difficult to assess at echocardiography. So these are a very important parts where 4D flow MRI can really help cardiologists to better understand and to better assess this lapse or dysfunction of the prosthetic valves.

In the evaluation of the great vessels, you discuss and illustrate the use of 4D flow in patients with bicuspid aortic valves and associated aortic aneurysm, aortic coarctation, Takayasu arteritis, and pulmonary hypertension. Importantly you review the use of this technique in the evaluation of patients post-endovascular thoracic and abdominal aortic aneurysm repair. Let’s look at Movie 10, which is also Figure 17, that nicely demonstrates a type 1 endoleak in a patient status post endovascular repair of a type B aortic dissection.

So in the case of this patient, surgeons and endovascular radiologists were discussing if it was a type I or type II endoleak and as you can see, we did this imaging, we don’t have a lot of artifacts and we can see very easily the false lumen, the true lumen, the leak during systole going from the true lumen to the false lumen and we see that it’s type I endoleak so they just came and put an under-graft, the correct under-graft displaced and that disappeared. It’s also very interesting to see that during diastole, you have a backflow from the false lumen to the true lumen. Concerning other processes, as you see when they are in (inaudible)we don’t have a lot of artifacts for abdominal and (inaudible) you see that you can really see the type of endoleaks and really plan the endovascular procedure after that.

Terrific. So after you briefly touch on some emerging applications of 4D flow MRI subsequent to the evaluation of cerebral aneurysm and arterial venous malformations. The paper provides a concluding section, when to choose between 2D and 4D flow MRI. In your own words, can you tell our listeners what factors to consider when employing these techniques for cardiovascular applications?

All the fields we use 2D PC can be are very interesting indications for 4D flow MR. The thing is that the more complex is the cardiac disease and the more you have to do different sequences at different points of 2D PC the more it is interesting to do one single 3D volume and 4D flow MR actually, or you can go at any point and do your measurements. At the end of the day, it goes actually faster to do maybe one whole sequence of six minutes than try to do many different measurements which may be not optimal because you are not in a good axis, you don’t see a really good all the vessels; and as I told you mostly in complex cardiac diseases. The other thing which is very useful using 4D flow MR is that you see that in dilated red vessels like dilated ascending aorta or dilated pulmonary artery, you have a lot of turbulences, you have vortical flows and you have helical flows. And these vortical flows are a source of errors for the measurements. With a 4D flow you can see easily all these flows and avoid these flows in your measurement. You can choose the optimal plane to do your measurements and this is one of the biggest help of 4D flow for these measurements. And sometimes when you see all this different turbulences in an aorta, you wonder how you do it when you do this 2D PC measurements blindly actually of all these turbulent flows.

Would you agree that in patients in which the surgeon wants more information about shunts post-Fontan, it sounds like those patients or your congenital heart disease patients in particular when you have a specific question to answer the 4D flow techniques could be really useful in some of these post-operative patients. Would you agree that seems to be one of the primary indications at this point in time?
AA  Yes, it is indeed. I would push it to a lot of different indications for all radiologists, but of course the congenital diseases and mostly the Fontan diseases is very good and relevant indication because you have a lot of things to measure and you have to see where goes all the blood flow and it has already made changes this visualization of the distribution of the blood flow coming from the different vena cava and people try to think differently. Cardio pediatrics, but also surgeons try to lever some new techniques.

JSK  Arshid, can you just share with us for a moment, even since you wrote and developed this paper for the Journal, it sounds like you're working on some new sequences and new techniques in 4D flow, maybe you can explain to the audience what those entail.

AA  Yes of course, one limit we have with this 4D flow sequence is that we have to choose before we run the sequence the maximal velocity encoding speed. We fix it usually ten percent higher than the expected maximal velocity, but maybe our expectation are a bit lower or higher than what it is really. So sometimes we use the 2D PC contrast phase sequences to check if there's some (inaudible) or not, but now as I promised, kind of promised in the paper, we have already multiple VENC and we are using already very good and promising prototypes of dual VENC sequences which enable to have low flows optimally and also assess optimally high flows without any loss of information.

JSK  Terrific. Well Dr. Azarine I'd like to thank you for taking the time today to discuss your paper on the cardiovascular applications of 4D flow MRI which can be found in the current May 2019 issue of RadioGraphics. I'll also point out to our listeners that there is an accompanying editorial by Dr. Karen Ordovas from the University of California, San Francisco who provides some expert commentary on this current paper. So Arshid thank you so much for your time today.

AA  Thank you. Thank you very much.