The role of susceptibility weighted imaging (SWI) in musculoskeletal radiology as an alternative to computed tomography (CT).

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Learning objectives

• To highlight the role of SWI in musculoskeletal radiology especially in the pediatric population.
• To go through basics of SWI imaging.
• To present myriad of the pictorial assay with SWI imaging including 3D constructed SWI images.
Background

Not all MRI images are created equal. K space data is transformed into image data using Fourier transform. This image data can be analyzed to give magnitude and phase images.

In 1981 Oppenheim et al wrote about the importance of phase imaging. The example from their paper depicts the importance of phase. Fig. 3 on page 7

For more than 20 years phase information went unutilized in clinical MR imaging. Magnetic inhomogeneity was viewed as the problem but some researchers like Yamada et al and Haacke et al viewed it as a solution rather a problem.

Yamada et al in 1996 showed the magnetic inhomogeneity artifact in detecting intracranial calcium. In 1997 Reichenbach et al using paramagnetic properties of deoxyhemoglobin showed it is possible to depict even the smaller veins in the brain. The same principle was used to detect iron in intracranial pathologies using SWI by Haacke et al. Haacke et al used the phase images and their research hinted the beginning of the new era which would take another 10 years to come in as practical application.

Now SWI is widely being used in brain imaging, Beauchamp et al have suggestive that SWI is better than CT and spin echo MR in detecting traumatic lesions in children. Huang et al demonstrated SWI could detect cerebral microbleeds. Even though capabilities of SWI in detecting calcium has been shown from early papers like Yamada et al and Haacke et al, it was hardly used in musculoskeletal radiology. We hypothesize that SWI would be of great help in characterizing the lesions which have components susceptible to the magnetic field. As bone contains calcium, the lesions containing bony components can be demonstrated with SWI. We especially wanted to see pathological components in the tumor for which follow up imaging with CT scan is often required. We thought if we could show the same features on SWI then follow up CT can be avoided especially in young patients. Ashwal et al have demonstrated SWI is very sensitive for predicting outcome in pediatric traumatic brain patients. Yamada et al and Barbosa et al have shown SWI can differentiate between calcification and hemosiderin deposition e.g. in hematoma. In musculoskeletal imaging identification of calcification is crucial in characterizing various lesions. Therefore we hypothesized SWI could also be usual in detecting calcification and differentiating it from a hematoma.

The principle of SWI:
As the name implies susceptibility weighted imaging detects inhomogeneity in the magnetic field. Stronger the paramagnetic or diamagnetic property of a molecule, stronger will be signal. And weaker paramagnetic and diamagnetic molecules will give a weak signal.

The following 3D diagram depicts this principle.

![Fig. 1: This 3D image shows the basis of SWI. Strong paramagnetic or diamagnetic molecules interact with magnetic field of MRI magnet. This regional distortion of magnetic field is picked up by the phase image reconstruction which then superimposed with magnitude image to give susceptibility weighted image.](image)

**References:** Akshaykumar, www.littleradiologist.com

As described by Yamada et al bone minerals, calcifications in tumors and dystrophic calcification are composed of calcium hydroxyapatite or apatite-like minerals, which is strong diamagnetic compared to adjacent tissue. We hypothesized this principle would be especially useful in musculoskeletal imaging where bone mineral and tumor calcifications are important. Phase shift induced by calcification is expected to be opposite of hematoma which contains deoxyhemoglobin, methemoglobin, hemosiderins and ferritins.

SWI has been used for detection of calcification and hemosiderin deposits in diagnosis of the various neurological disorders including stroke [12], traumatic brain injury [13][14][15],...
Dementia, hemorrhagic disorders and neuro-infectious conditions, epilepsy, Parkinson's disease. We are trying to see the application of SWI beyond neuroimaging, extending it in the field of musculoskeletal radiology especially in pediatric population, as an alternative to CT scan. CT scan has been a workhorse of the imaging for the musculoskeletal system but in the pediatric population, if MRI could be shown to be as efficient in detection of calcification it will become a viable alternative to CT especially in follow up scans. Some authors like Eley et al have written about "black bone imaging" to improve bone and soft tissue demarcation in head and neck imaging as a preliminary study. We have used SWI in as a novel indication of musculoskeletal imaging. While doing literature search we found no study using SWI in musculoskeletal imaging. It is critical that we find the application of MRI in musculoskeletal system to detect calcification and to decrease our dependence on the CT scan. This will, in turn, decrease the radiation dose to our patients especially in the pediatric population.
Fig. 1: This 3D image shows the basis of SWI. Strong paramagnetic or diamagnetic molecules interact with magnetic field of MRI magnet. This regional distortion of magnetic field is picked up by the phase image reconstruction which then superimposed with magnitude image to give susceptibility weighted image.

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Fig. 2: One of the earliest mentions of importance of phase images can be found in this article written by Oppenheim et al.

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Fig. 3: The images demonstrate how without phase information in images t becomes distorted. From this examples one can see phase information as important if not more important than magnitude information.

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Findings and procedure details

MRI was performed with 3Telsa (Skyra Siemens). SWI imaging was done by applying SWI sequence from brain protocol as SWI dedicated to musculoskeletal imaging is not available. We modified FOV to suit the lesion. SNR was maintained at >=1.

We will discuss myositis ossificans as the example case for the role of SWI in musculoskeletal radiology. One of the key hallmarks of myositis ossificans is zoning phenomenon. Where new bone formation is seen from outside to inside which is helpful in differentiating from extra-osseous osteosarcoma in which the bone formation is from center to periphery. It is crucial to identify this zoning phenomenon to make the diagnosis of myositis ossificans and for that CT scan is routinely done as it is thought that MR cannot detect the subtle zoning phenomenon especially in early stages. Our findings challenge this notion, as we could not only see the zoning phenomenon as good as CT on SWI sequence of MR imaging, but we also could see features which CT could not pick up. One of those being demonstrating no continuity with bone marrow of adjacent femoral shaft, this is particularly important in this case as this lesion was very hyperintense on T2 weighted imaging and showed superiorly reaching till the cortex of femur on CT (Fig. 6 on page 13), and therefore osteochondroma transforming into the chondrosarcoma was also considered as differential on CT. But with MRI we could rule this out, on SWI images we also could see the stalk-like structure without bone marrow connection, in this aspect SWI scored over CT scan.

MR also showed the disproportionately large area of vasogenic edema in surrounding soft tissues which is showing T2 shine through (hyperintense on diffusion-weighted imaging and not showing restriction of diffusion on ADC maps). This disproportionately large soft tissue edema is one of the soft signs that the lesion is not likely malignant as adjacent fascia is still intact and therefore causing edema.

SWI could detect the periosteal reaction as good as that of CT scan. In this case, there was the periosteal reaction in the shaft of the femur. SWI was more accurate than CT in showing the multi-laminate appearance of periosteal reaction (Fig. 5 on page 12 Fig. 6 on page 13). Periosteal reaction is not always malignant and it has been described in myositis ossificans[23]. Therefore the presence of periosteal reaction should not decrease the confidence in the diagnosis of myositis ossificans.

It is shown in

Myositis ossificans is one of the no-touch lesions having the radiological diagnosis. Because there is a human being at the other end of the needle and it's our job to abide by Primum non nocere ("first do no harm"). Biopsy if done should not be done from the core
of the lesion as it will contain immature cells which pathologist may mistake for malignant etiology. The external zone of heterotopic ossification should be taken as it will contain osteoblasts and will make the diagnosis easier for pathology colleagues, as they get only small part of lesion it is also important to convey the whole picture of the lesion.

One of the rationalizations for CT is often put as the ability to render the lesion in 3D. This makes communication with surgeons easier and also helps in explaining patient. We used SWI to create the 3D rendering of the lesion and they showed comparable quality with CT rendered images (Fig. 10 on page 16 Fig. 11 on page 16). Details in CT rendered 3D were more because of thin slices, but SWI also deep comparable job and without the ionizing radiation exposure.

**Fig. 10:** 3D rendered image of CT on the left side. All other images are 3D rendered SWI images. On the extreme right the sculpted lesion rendered with SWI is seen.

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T2 and T1 weighted spin echo sequences could not pick up the zoning phenomenon when compared to SWI and CT. This would suggest adding SWI is important as one may not suspect the ossification or calcification on spin echo sequence itself. This also may cause misdiagnosis and err towards more malignant diagnosis as had happened with this case. Patient when had undergone MR for the first time the differentials were given as para-osteal osteosarcoma. While CT did pick up zoning phenomenon it could not comment on the bone marrow continuity and therefore MR re-evaluated. In this way, we could go in circles from MR to CT and then back to MR, and therefore adding sequences
in MR for characterization of ossification, calcification and hematoma would be of great help to patients. This will decrease the overall cost required for re-imaging with CT and would avoid the radiation dose to young patients.

**Fig. 7**: On T2 weighted images the lesion appears very hyperintense, on T1 weighted images it is isotense to adjacent muscles. In both T1 and T2 weighted images the peripheral ossification in this lesion is not appreciable. It can be readily visualised in SWI and comparable to CT image of same section.

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While using SWI imaging for the musculoskeletal system we could not resist applying it to other systems. Especially we were interested in 3D reconstruction rendering of SWI images. In case of choroidal melanoma where melanin is highly paramagnetic SWI 3D construction was very detailed. (Fig. 14 on page 18)(video can be seen [here.](#))
Fig. 4: A) A 12 year old girl presented with swelling in right thigh after falling off bicycle 2 months ago. Radiograph of femur AP view showing the well defined lesion with peripheral rim of ossification around it, also there is periosteal reaction seen in shaft of femur adjacent to the lesion. B) 3D reconstruct of CT scan showing the zoning phenomenon. C) MRI showing hyperintense lesion on STIR images with surrounding soft tissue edema
Fig. 5: SWI image shows the zoning phenomenon of peripheral ossification. Compare with CT image there is no difference in thickness of the ossification on CT and SWI images. On coronal images CT shows the stalk like projection from lesion reaching to the femur, on SWI images that stalk does not show any medullary connection. Also the perilesional edema can also be appreciated on SWI. Also note the multi laminated periosteal reaction is better visualised on SWI images than CT on coronal reformat.

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**Fig. 6:** Zoning phenomenon is visualised on SWI images with few foci of ossifications are also seen in inside the zone of ossification, this suggests centripetal direction of ossification.

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**Fig. 7:** On T2 weighted images the lesion appears very hyperintense, on T1 weighted images it is isotense to adjacent muscles. In both T1 and T2 weighted images the peripheral ossification in this lesion is not appreciable. It can be readily visualised in SWI and comparable to CT image of same section.

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**Fig. 8:** There is a stalk like projection seen on CT which not readily visible on T2 weighted and T1 weighted sequences. But it is conspicuously seen on SWI images.

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**Fig. 9:** Zoning phenomenon is seen on SWI as good as CT image. Not that it inconspicuous on T1 and T2 weighted images.
Fig. 10: 3D rendered image of CT on the left side. All other images are 3D rendered SWI images. On the extreme right the sculpted lesion rendered with SWI is seen.
**Fig. 11:** The myositis ossification lesion is readily appreciable on 3D rendered image on frontal projection. Note the thickness of the peripheral zoning phenomenon.

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Fig. 12: The 3D rendered image viewed from above, note the zoning phenomenon is appreciated and details of the image is comparable to the 3D reconstruction of CT images.

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Fig. 13: 3D reconstruction of ankle joint. Compared with 3D T2* DESS images 3D SWI images give more details about bone while in DESS rendering bones are almost invisible.

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**Fig. 14:** Choroidal melanoma is seen on T1 weighted images as hyperintense because of its paramagnetic properties. We decided to use this same property to visualise this tumor using SWI and then rendering it in 3D, we then showed the 3D interactive object to medical students and they loved it.

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Conclusion

Our initial experience with small cases has shown that SWI is useful in many cases where CT was thought as the only option. Even though SWI imaging in musculoskeletal is novel and exciting, the prospective study is needed to see the advantages and limitation of SWI over CT. It would be also interesting to find what would be indications of SWI over doing a CT scan. As we will explore further maybe we could prevent the radiation exposure in many indications, especially to our young patients.

What science has taught us is central dogmas should be challenged with newer ideas. To come up with evidence to replace old methods. The journey of SWI has already taken a long time from its inception to being realized as a clinically relevant imaging in the brain, now it is time to take it further, to help it blossom and "bloom".
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