

# Improved Visualization of Femoroacetabular Impingement Cartilage Damage with Multiband Simultaneous Multi-Slice Acceleration

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## Introduction

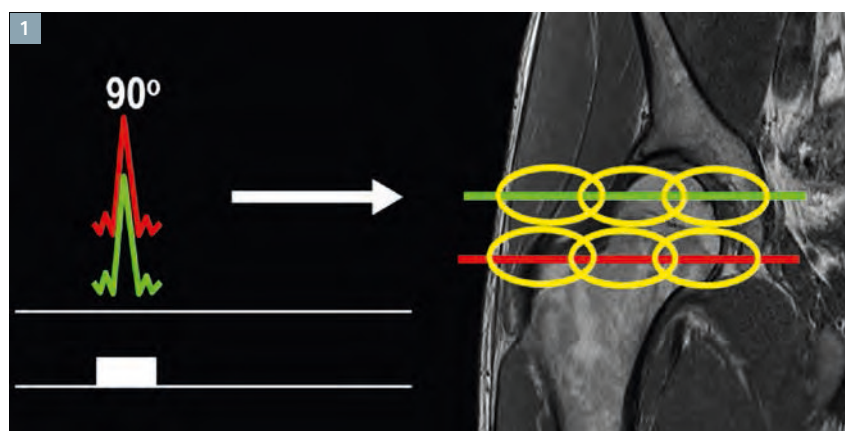
Femoroacetabular impingement (FAI) is a common source of hip pain in adults caused by a pathological abutment of the head-neck junction of the femur and the acetabular rim of the hip [6]. This abutment leads to mechanical friction, which can in turn cause labral and chondral lesions and lead to osteoarthritis (OA) [1, 2, 4, 5, 8]. The recommended treatment for FAI is joint preservation surgery if a labral tear has occurred, cartilage damage is not severe, and patient symptoms cannot be managed conservatively with physical therapy [3, 10, 11]. In FAI, cartilage damage is typically limited to the acetabulum and occurs deep within the tissue as a debonding of articular cartilage from underlying bone [2]. This so-called 'cartilage delamination' is the hallmark of the disease. If cartilage damage is severe, as would be the case if there was prevalent cartilage delamination, then joint preservation surgery will fail and total hip replacement will be necessary. Therefore, in order to appropriately recommend treatment for FAI, imaging is needed to evaluate the hip joint for both labral tears and cartilage delamination.

However, cartilage delamination is not seen using current clinical imaging protocols because spatial resolution is insufficient. The necessary resolution cannot be achieved due to prohibitively long acquisition times. Additionally, labral tears can be difficult to diagnose, also due to limited spatial

resolution. Specifically, slices of 3 to 4 mm are too thick, leading to problematic volumetric averaging within voxels along the curved surface of the acetabulum that obscures the cartilage and labral pathology. Multiband Simultaneous Multi-Slice (SMS) acceleration technology [7, 9] can be used to improve the spatial resolution while not increasing the acquisition time (or, equivalently, reducing the acquisition time for a given spatial resolution). Multiband allows multiple imaging slices to be excited simultaneously, thereby enabling more slices (and

thus higher spatial resolution) to be acquired within a given acquisition time. In this study, we evaluated the potential clinical benefits of utilizing a multiband SMS accelerated turbo spin echo (TSE) sequence<sup>1</sup> to either improve diagnostic accuracy of cartilage delamination and labral tears or save scan time while maintaining diagnostic image quality.

<sup>1</sup> The product is still under development and not commercially available yet. Its future availability cannot be ensured.



**1** Multiband excitation allows multiple slices to be acquired during one acquisition. In this diagram, a multiband simultaneous multi-slice acceleration factor of two is illustrated. The red and green slices passing through the femoral head are excited and refocused simultaneously using two selective RF pulses. The acquired signal is then received by a multi-channel receive coil array placed about the hip (yellow circles), which have sensitivity profiles that are unique at each slice position. Using the spatial dependence of the array sensitivity profile, aliasing artifacts caused by the simultaneous slice excitation are corrected during image reconstruction.

## Case 1

A 58-year-old patient suffered left hip pain for 5 years and pain got exacerbated with prolonged periods of running. A labral tear was clearly identified using the SMS-accelerated T1-weighted TSE sequence with fat saturation (slice acceleration factor 2) following the administration of intra-articular gadolinium contrast agent (MR arthrogram), which provided high spatial resolution (2.0 mm slice thickness) in a clinically feasible acquisition time (Fig. 2). Bright contrast-enhanced signal is seen within the chondrolabral junction. However, the standard resolution acquired for the clinical exam (3.0 mm slice thickness) was insufficient and the labral tear could only be vaguely seen due to partial volume averaging.

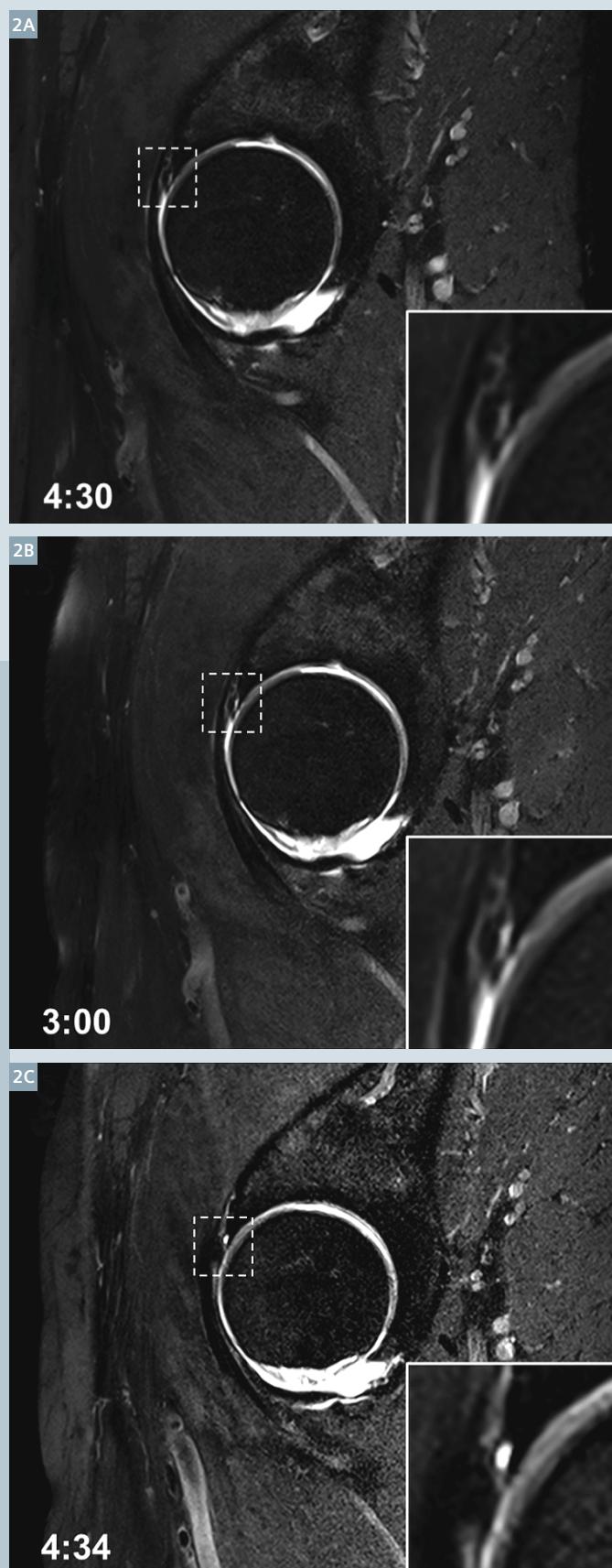
- 2 Multiband SMS acceleration provides sharper visualization of a labral tear using 3T MR arthrography. (2A) Standard clinical MR arthrogram utilizing a T1-weighted TSE sequence with fat saturation. The region with the labral tear (dashed box) is zoomed-in and shown in the lower-right corner. The labral tear, identified by contrast-enhanced fluid infiltration into the chondrolabral junction, cannot be confidently diagnosed at the acquired spatial resolution. (2B) Applying multiband SMS acceleration enables the same image quality in (2A) to be obtained in a reduced acquisition time (3:00 min vs. 4:30 min), but this does not solve the spatial resolution deficit. (2C) Utilizing the time-savings provided by multiband SMS acceleration to increase spatial resolution for the same acquisition time as in (2A) provides a much sharper depiction of the labral tear, allowing clear clinical diagnosis.

**Imaging parameters of the MR arthrogram:** FOV 180 × 180 mm<sup>2</sup>, matrix size 384 × 384, in-plane resolution 0.47 × 0.47 mm<sup>2</sup>, 20% slice spacing, excitation/refocusing flip angle 90°/120°, readout bandwidth 195-215 Hz/pixel, in-plane GRAPPA acceleration factor 2, T1-weighted with spectral fat saturation, ETL 4;

**Standard TSE:** 3 mm thickness, 30 slices, TR 656 ms, TE 13 ms, 100% phase oversampling, 4 concatenations, TA 4:30 min;  
2 mm thickness, 46 slices, TR 631 ms, TE 12 ms, 100% phase oversampling, 6 concatenations, TA 6:30 min;

**Multiband SMS Accelerated TSE:** slice acceleration factor 2, 3 mm thickness, 30 slices, TR 656 ms, TE 13 ms, 160% phase oversampling, 2 concatenations, TA 3:00 min;  
2 mm thickness, 46 slices, TR 631 ms, TE 12 ms, 100% phase oversampling, 4 concatenations, TA 4:34 min.

Images acquired with MAGNETOM Skyra 3T MR scanner (Siemens Healthcare, Erlangen, Germany)





## Case 2

A 25-year-old male, who played hockey in high school, presented with left hip pain. Cartilage delamination was identified in a clinically feasible acquisition time using multiband SMS accelerated T2-weighted TSE with fat saturation and a slice acceleration factor of two (Fig. 3). The higher spatial resolution provided by multiband SMS acceleration (2.0 vs. 3.0 mm slice thickness) depicted debonding of articular cartilage from the underlying bone in the acetabulum as revealed by slightly higher signal interposed between the underlying bone and the dark line of the superficial layer of the cartilage. While the subjacent normal

cartilage has a smooth thin surface and a homogeneous intermediate intensity signal, the area of delamination has a slightly higher intensity signal with a surface that appears darker, thicker, and slightly wavy. The border between the normal cartilage and the abnormal debonded cartilage has a vertical gray line. However, without slice acceleration and the resultant increase in spatial resolution, the cartilage delamination could not be identified. The acquisition time would be prohibitively long if the desired spatial resolution was acquired without multiband SMS (6:30 min vs. 4:34 min).

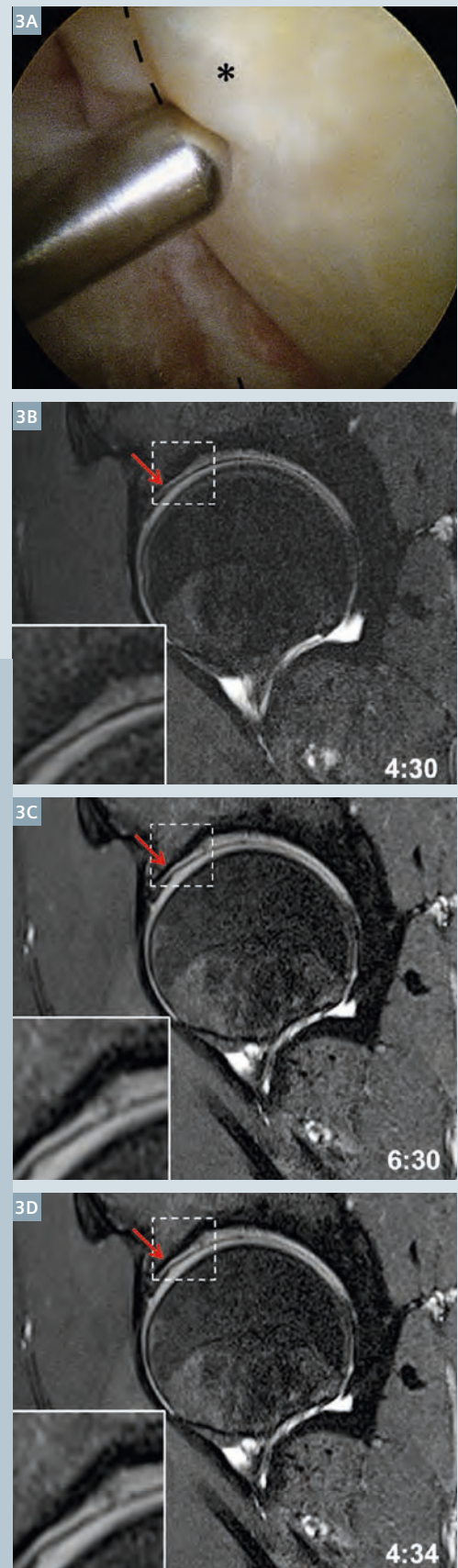
**3** Multiband SMS acceleration enables identification of cartilage delamination in a clinically feasible acquisition time. **(3A)** Representative image taken during arthroscopic surgery probing of the articular cartilage of the acetabulum in another patient [12]. As the probe pushes against the cartilage, a bulge is seen (\*), which indicates that the cartilage has debonded from the bone. The dashed line reveals the chondrolabral junction, with the acetabular labrum identified to the left of the dashed line. The cartilage can be seen to be attached to the bone to the right of the asterisk (\*). **(3B)** In the pre-operative standard clinical T2-weighted MRI protocol with fat saturation (3.0 mm slice thickness), the cartilage delamination is not well visualized and cannot be confidently diagnosed. The red arrow points to the location probed in (3A), and the region of delamination is outlined by the dashed box (zoomed-in at the lower left corner). **(3C)** If the slice thickness is reduced from 3.0 to 2.0 mm, the cartilage delamination can be clearly seen. However, this increase in spatial resolution comes at the cost of increased acquisition time (6:30 vs. 4:30 min). **(3D)** Multiband SMS enables slice thickness to be reduced to 2.0 mm while maintaining a reasonable acquisition time (4:34 min). Note that the image quality is comparable to the result in (3C) despite being >30% faster.

**Imaging parameters:** FOV 160 × 160 mm<sup>2</sup>, matrix size 320 × 288, in-plane resolution 0.50 × 0.56 mm<sup>2</sup>, 20% slice spacing, excitation/refocusing flip angle 90°/140°, readout bandwidth 180-260 Hz/pixel, echo spacing 12 ms, T2w with spectral fat saturation, ETL 12, hyper-echo;

**Standard TSE:** 3 mm thickness, 26 slices, TR 4580 ms, TE 52 ms, 100% phase oversampling, TA 4:30 min; 2 mm thickness, 38 slices, TR 6680 ms, TE 52 ms, 100% phase oversampling, TA 6:30 min;

**Multiband SMS Accelerated TSE:** slice acceleration factor 2, 2 mm thickness, 38 slices, TR 4200 ms, TE 52 ms, 120% phase oversampling, TA 4:34 min.

Images acquired with MAGNETOM Prisma 3T MR scanner (Siemens Healthcare, Erlangen, Germany)



## Methods

Patients with hip pain undergoing a clinical MR evaluation (current standard of care) for FAI were imaged using both a clinical and a multiband SMS accelerated sagittal multi-slice 2D TSE sequence with fat saturation under an Institutional Review Board approved protocol for which informed consent was obtained. Imaging was done using Siemens 3T MRI systems (MAGNETOM Skyra and MAGNETOM Prisma, Siemens Healthcare, Erlangen, Germany) with an 18-channel flex body coil wrapped about either the right or left hip in combination with an integrated 32-channel spine coil array. This enabled unilateral imaging of the hip joint for higher spatial resolution by limiting the receive coil sensitivity to one side of the body to avoid signal wrap.

Multiband technology was used to simultaneously excite and acquire more than one imaging slice simultaneously (Fig. 1). Multiband RF pulses were generated for simultaneous multi-slice excitation and echo refocusing, and the VERSE technique was applied to the RF pulses to reduce peak power and SAR. A low-resolution multi-slice 2D GRE scan integrated into the SMS TSE sequence was used as the reference scan to obtain the coil sensitivities. Image reconstruction techniques based on parallel imaging methodology were then used to unalias the signal acquired for the multiple slices.

## Discussion

Accurate assessment of the acetabular cartilage is fundamental to the evaluation of and the clinical decision-making for patients with symptomatic FAI. Patients with moderate to advanced cartilage degeneration will fail arthroscopic repair, leading to total hip arthroplasty. Multiband SMS acceleration technology enables higher spatial resolution to be acquired with minimal impact on image quality and no increase in acquisition time. As shown in the two clinical cases, this technique provides improved diagnostic information that can better inform treatment decisions. In our initial clinical experience, we found that the multiband SMS accelerated TSE sequence can provide 30% higher spatial resolution within a given acquisition time to improve diagnostic accuracy of cartilage delamination and labral tears, or alternatively over 30% time savings for a given spatial resolution while maintaining diagnostic image quality. In general, multiband SMS acceleration will enable higher-quality imaging protocols for clinical 3T applications by targeting higher resolution to allow for more diagnostic accuracy in a standard clinical setting.

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