Case study 1: Multi-Slice in Musculo-Skeletal MR on Siemens Sola (XA31)

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Introduction

The Leeds Teaching Hospitals NHS Trust (LTHT) operates a 1.5 T magnetic resonance imaging (MRI) scanner at Chapel Allerton Hospital in Leeds. This scanner is used almost exclusively for musculoskeletal (MSK) MRI. Due to appointment times increasing because of social distancing restrictions during the covid-19 pandemic, waiting lists for MSK examinations increased creating a backlog of patients. Additionally, the scanner started a new service to investigate fractured scaphoids, equating to an additional 8 referrals a week.

One way to tackle this patient backlog and increase in referrals is to decrease scan times. This work was carried out in the first half of 2022 and used acceleration techniques that were available on the scanner but had not yet been fully exploited.

Methods – Staffing, Scanner and Sequence Information

All work was carried out on a Siemens Magnetom Sola scanner (Software version XA 31) and focused on applying SMS to speed up existing turbo spin echo (TSE) imaging sequences, although additional time savings were also sought on top of those provided by SMS. The following coils were used to image different anatomies:

- Tx/Rx Knee 18 MR Coil 1.5T
- foot ankle coil
- Large and small ultraflex 18
- Body 18
- Spine 32
- Hand wrist 16

The MSK scanner in Chapel Allerton hospital has in house physics support equivalent to 1.0 WTE. This service optimisation was led by a team of one physicist, one radiographer and a Siemens Healthineers MR Product Application Specialist, with support from the MRI physics department at LTHT and MRI radiographers at Chapel Allerton hospital.

Imaging sequences in the following anatomical areas were optimised:

- knees
- ankles
- elbows
- hips
- wrists - for scaphoid fractures
- hand - sarcoma sequences

Images were optimised during clinical scanning. Four half day sessions were selected when the Siemens Product Application specialist could visit the department and patients were booked with longer time slots to allow time to acquire the additional sequences. Patients were booked so that each session could focus on only two anatomies.

Image quality was initially assessed by the radiographers and physicists and those that appeared to be of clinical quality were passed on to radiologists for assessment. Radiologist feedback was sought on image quality as scanning was on-going where possible. Feedback was received from either a consultant radiologist or clinical fellow on most sequences. All sequences, including those being developed were archived to PACS. If radiologist feedback was positive, or no radiologist feedback was received, the optimised sequences replaced the original ones in the clinical workflow. For a workflow of the methodology see *Figure 1*. Older sequences were archived and saved on the scanner and on an external drive so they could be bought back if there were issues later with the optimised sequences.

The overall physics time required was approximately 4 days (4 x half days scan sessions and approximately 4 x half-days of prep and collecting radiologist feedback and editing final protocols).

All work took place in February and March 2022.

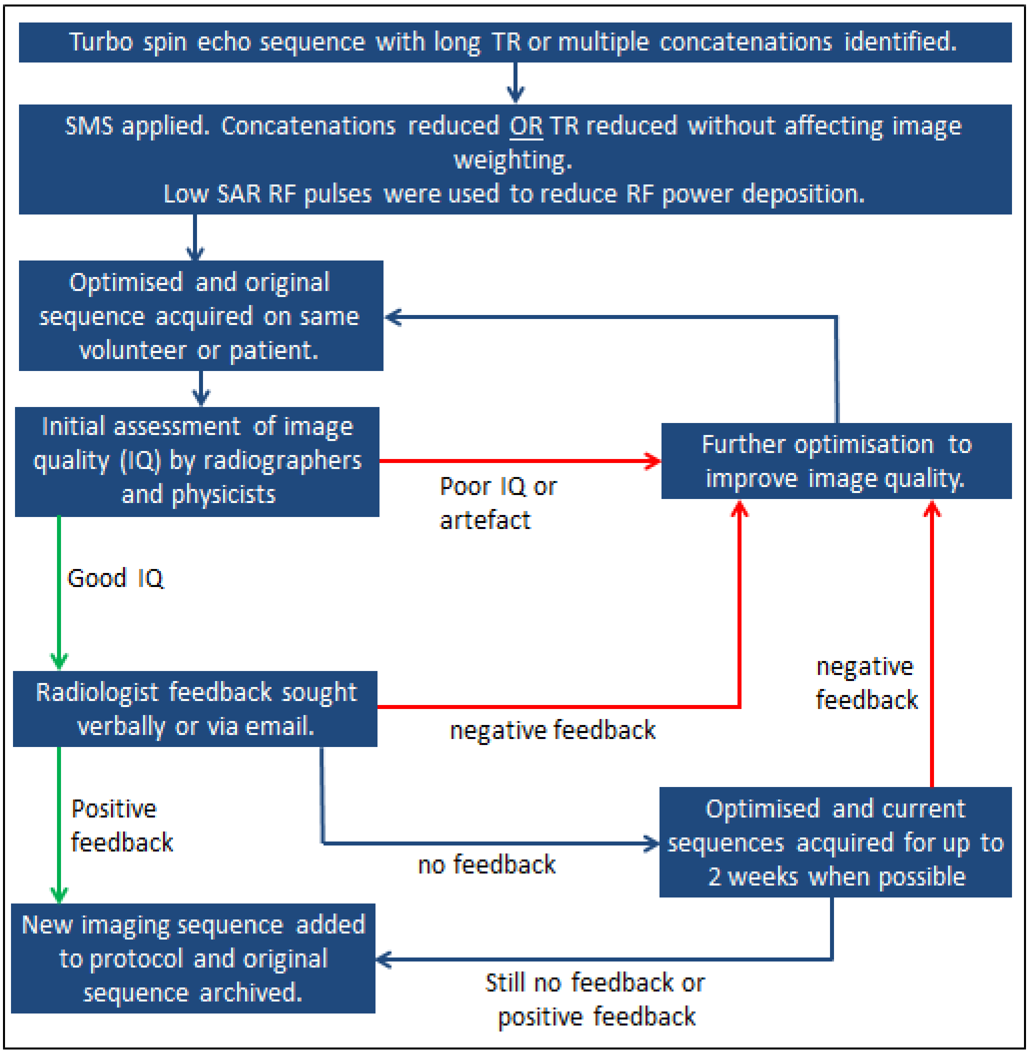

Figure 1: *Methodology for the optimisation work*

Results

Scan time reductions and parameter changes post optimisation are shown in Table 1. Overall reduction in MR scan times for each of the anatomical areas optimised are shown in Table 2.

Table 1: key sequence parameter changes pre- and post-optimisation for each anatomical area, and scan time reductions for each sequence.

Sequence name	Time mm:ss		Time savings mm:ss (%)	Changes
	Pre	Post		
Knee				
pd tse fs tra	4:47	2:27	2:20 (48.7%)	Added SMS (SMS = 2) and reduced TR (4160 ms - 3000 ms)
t2 tse fs sag	5:21	2:32	2:49 (52.6%)	Added SMS (SMS = 2), reduced TR (6030 ms - 3540 ms)
Ankles				
pd_tse_tra	2:20	1:00	1:20 (57.14%)	Added SMS (SMS = 2), reduced TR (3800 ms -2500 ms)
t2_tse_fs_tra	2:16	1:21	0:55 (40.44%)	Added SMS (SMS = 2), reduced TR (4000 ms - 2500 ms)
pd_tse_cor_fs	3:44	2:22	1:22 (53.95%)	Added SMS (SMS = 2), reduced TR (3940 ms - 2500 ms)
t2_tse_fs_sag	2:48	1:51	0:57 (33.93%)	Added SMS (SMS = 2), reduced TR (4560 ms - 3000 ms)
t1_tse_sag	2:32	1:10	1:22 (53.95%)	Added SMS (SMS = 2), reduced concats frm 2 to 1
Elbow				
pd_tse_tra	4:28	3:02	1:26 (32.09%)	Added SMS (SMS = 2), reduced TR
t2_tse_fs_tra	2:22	1:31	0:51 (35.92%)	Added SMS (SMS = 2), reduced TR
t1_tse_cor	3:50	2:12	1:38 (42.61%)	Added SMS (SMS = 2), reduced TR
t2_tse_fs_cor	2:22	1:31	0:51 (35.92%)	Added SMS (SMS = 2), reduced TR
pd_tse_fs_sag	2:51	2:06	0:45 (26.32%)	Added SMS (SMS = 2), reduced TR
Hips (unilateral)				
T1 tse cor	04:38	02:15	2:23 (51.44%)	Added SMS (SMS = 2), reduced concats from 2 to 1
Pd tse tra oblique	03:32	02:03	1:29 (41.98%)	Added SMS (SMS = 2), reduced concats from 2 to 1
Pd tse fs sag	04:41	03:12	1:29 (31.67%)	Added SMS (SMS = 2), reduced TR (3650 ms - 2500 ms)
Pd tse fs cor	04:41	03:12	1:29 (31.67%)	Added SMS (SMS = 2), reduced TR (3650 ms - 2500 ms)
Scaphoid				
T1 tse cor	3:42	1:41	2:01 (54.50%)	Added SMS (SMS = 2), reduced concats from 2 to 1
T2 tse fs sag	4:08	1:59	2:09 (52.02%)	Added SMS(SMS = 2), reduced concats from 2 to 1, reduced TR (3900 ms - 2500 ms)
Hand				
T1 tse cor	03:02	01:48	1:14 (40.66%)	Added SMS(SMS = 2), reduced concats from 2 to 1
T1 tse fs tra	05:19	02:59	2:20 (43.89%)	Added SMS (SMS = 2), reduced concats from 5 to 3 and reduced TR (983 ms - 860 ms)

Figure 2 shows pre-optimised and optimised images for an ankle and knee. Figure 3 shows pre-optimised and optimised images for a wrist.

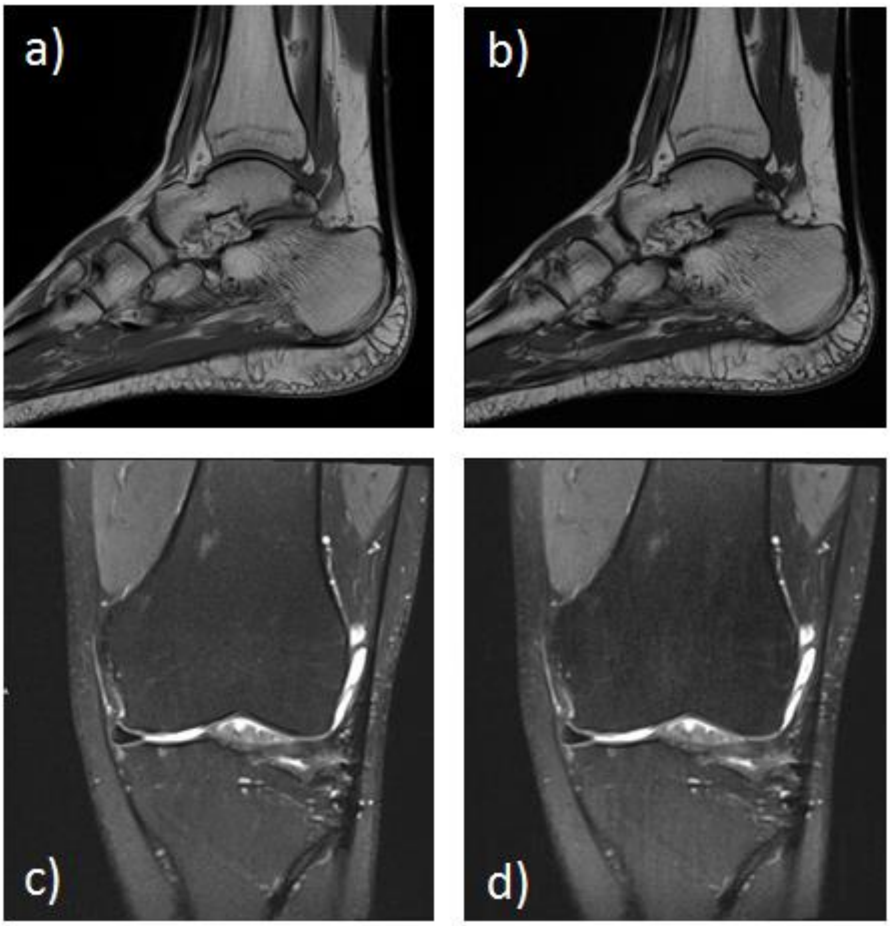

Figure 2: *a) pre-optimised T1 weighted ankle image, TA = 2 mins 32 seconds b) same image with SMS applied and concatenations reduced from 2 to 1, TA = 1 min 10 seconds. Over 50% scan time savings with no noticeable change in image quality c) pre-optimised proton density fat saturated coronal of a knee TA = 2 min 38 d) post optimised proton density fat saturated coronal image with SMS applied and the TR reduced. Radiologists were unhappy with image quality and so this was not used.*

Figure *3: a) pre-optimised T1 weighted coronal image, TA = 3 min 42 seconds) b) T1 weighted coronal image with parallel imaging (PI factor of 2) showing noise (red arrow), TA =1 min 40 seconds c) T1 weighted coronal image with SMS (SMS factor of 2) showing comparable image quality to the original sequence.*

Anatomical area	Total time savings
Knees	5 minutes 9 seconds (29% of total examination time)
Ankles	6 minutes 2 seconds (44% of total examination time)
Elbows	5 minutes 6 seconds (33% of total examination time)
Hips	9 minutes 20 seconds (34% of total examination time)
Scaphoids	5 minutes 17 seconds (25% of total examination time)
Hands (sarcoma)	4 minutes 39 seconds (32% of total examination time)

Table 2: overall reduction in MR scan times for each of the anatomical areas optimised.

An audit was conducted looking at scan times of ankle and knee scans. Timings of scans acquired between October - December 2021, before any optimisation work, and between April - June 2022, after optimisation was completed, were recorded. These results are shown in Table 3.

Anatomy	Time (pre optimisation)	Time (post optimisation)	Savings (min:sec)	Savings (%)
Ankles (left)	14:06	9:27	4:39	32.98%
Ankles (right)	15:09	7:21	7:48	51.49%
Knees (Left)	21:30	16:01	5:29	25.50%
Knees (right)	20:22	15:05	5:17	25.94%

Table 3: mean total time for acquisition of all sequences by anatomy

Appointment time changes due to these optimisations, amongst other reasons, are shown in Table 4. Based on these figures, the time savings of the recent optimisation work equates to 910 minutes or 15 hours and 10 minutes. Working off an average slot time of 27mins for these 5 parts, this provides 33 extra slots per month. Alternatively, these savings could provide time for 30 extra knee scans, 45 extra elbow scans, 20 extra hip scans, 45 additional ankle scans or 45 additional scaphoid scans.

	Appointment time before optimisation (minutes)	Appointment time after optimisation* (minutes)	Mean number of appointments per month (Apr - Jun 2022)
Knee	40	30	50
Ankles	30	20	8
Elbows	30	20	3
Hips	55	45	5
Scaphoids	30	20	20
Hands (sarcoma protocol only)	40	30	3

***Note that in addition to savings in imaging time, some of the reduction in appointment times arose due to a relaxation of Covid-19 cleaning requirements.**

Table 4*: appointment time changes.*

Discussion

This optimisation required a multi-disciplinary approach requiring involvement from MR physicists, radiographers, radiologists and the booking office. Input was also provided by a Siemens Healthineers MR Product Application Specialist with considerable experience in MSK imaging.

SMS can deliver high time savings in protocols with lots of TSE imaging and slices, without the SNR penalty associated with other acceleration methods such as parallel imaging. At our hospital the existing MSK protocols were predominantly TSE-based and were ideal candidates to be optimised using SMS due to very long TR's (for T2 and PD weighted sequences) and high numbers of concatenations (T1 weighted sequences).

In this optimisation we identified sequences with long TR's (> 3000 ms for T2/PD weighted imaging, >700 ms for T1 weighted imagining) or more than 1 concatenation. In general, we would then introduce SMS and reduce the TR or number of concatenations accordingly, which can result in scan time savings of approximately 50%. However, care must be taken that sequences do not hit Specific Absorption Rate (SAR) limits too easily. Often SAR can be reduced without eating into scan time savings by switching to low SAR pulses and reducing the flip angle as required (to a minimum of 120^{o}).

While there are some artefacts associated with using SMS, in general these did not appear. Image quality was reviewed by radiologists at the time of scanning and generally found to be acceptable, but those that weren't were either further optimised or left as their default sequence (see *Figure 2*). In sequences with long TR's or multiple concatenations without parallel imaging already applied, SMS provided comparable time savings for better image quality than adding parallel imaging (Figure 3). In sequences which already had parallel imaging, SMS could be often applied for further time savings. However, the utility of SMS was limited to sequences with a long TR or multiple concatenations. If the sequence was already well optimised there was very little added benefit to applying SMS.

As a result of this optimisation work and the reduction in cleaning requirements between patients as covid-19 restrictions were relaxed the appointment times of several anatomies were reduced, as shown in

Future Work

Since this optimisation work took place, the scanner has had a software upgrade to version XA 51, and the deep resolve software has been added. Work is still on going to optimise the existing sequences with SMS with deep resolve. Deep resolve can be used in conjunction with SMS; however our experience so far has been that using deep resolve with solely parallel imaging (grappa) provides better image quality than using it with a combination of parallel imaging and SMS (*Figure 4*). However, there has been some success applying maximum parallel imaging factors (4) with an SMS of 2 to create very fast scans (*Figure 5*).

Figure 4: a) T1 weighted coronal wrist image with SMS factor 2 b) T1 weighted coronal wrist image with Deep Resolve Boost and Sharp, SMS factor 2 and parallel imaging factor 2 c) T1 weighted coronal wrist image with Deep Resolve Boost and Sharp and parallel imaging factor 4. b) and c) both have similar acquisition times (52 and 51 seconds) and marked time savings compared to the original (1 minute 41 seconds) however radiologist feedback indicated that image c) had significantly better image quality.

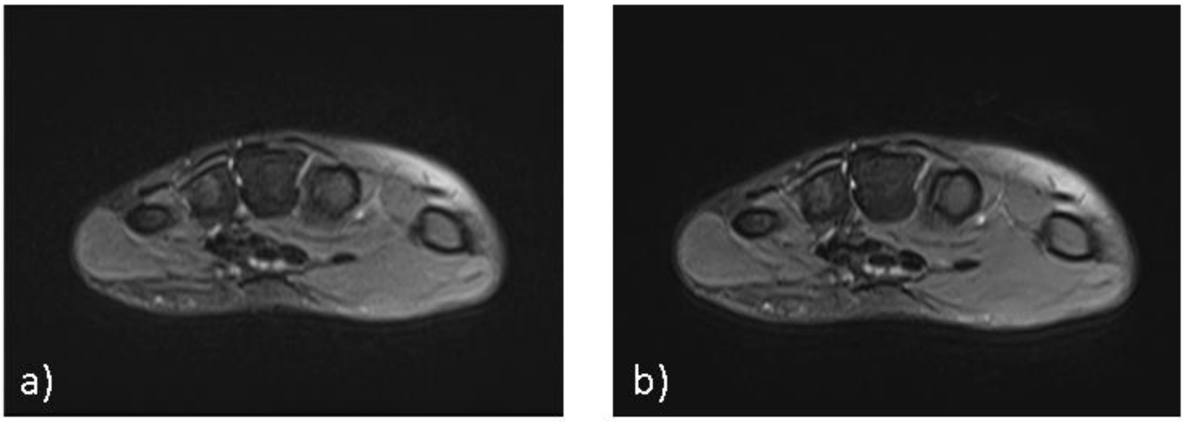

Figure 5: a) transverse t2 fat saturated image of the wrist with SMS factor 2 and parallel imaging factor 2 applied, b) same image with deep resolve boost and sharp applied and parallel imaging factor increased to 4, SMS factor kept at 2.

Conclusion

In this work MSK scans have been optimised predominantly using SMS to reduce scan time by up to 50% in some cases. The circumstances in which SMS can be added to imaging sequences to bring down scan time are quite specific, and its utility is limited to sequences with long TR's or multiple concatenations. However, many sequences in different anatomies in MSK imaging satisfy this requirement, resulting in increased patient throughput at the MSK 1.5 T scanner at Chapel Allerton Hospital in Leeds.